CONSTRUCTION PLANNING
AND PLANT

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To

THE MEN

OF

SKILL AND COURAGE

IN THE

CONSTRUCTION INDUSTRY

PREFACE

The contents of this book first appeared as a series of twenty-six articles in the McGraw-Hill publication *Construction Methods* from November, 1935, to March, 1938. Much of the subject matter is the same as that originally published, but all of it has been brought up to date and some new sections and reference tables have been added.

This work is largely an outgrowth of experiences in building the great dams in the Tennessee Valley. When that vast construction program was started late in 1933, the urgency to help relieve nationwide unemployment conditions demanded that construction be started almost simultaneously with the engineering planning. This resulted in placing unusual demands on a sound program of construction planning. The magnitude of the projects called for a broad vision and understanding of the requirements in construction plant and equipment, as well as close attention to detail, in order to assure a high efficiency of operation and correspondingly good job morale.

The first man selected by Arthur E. Morgan for the construction program of the Tennessee Valley Authority was Charles H. Locher, one of the country's veteran contractors with a wide range of experience. At considerable personal sacrifice he served as Construction Consultant for five years, and his vision and understanding contributed much to an effective start and the general success of the program. As mentioned later, he also participated in the writing of this book.

The magnitude of the Tennessee River projects brought together within comparatively few years a greater variety of construction operations than has probably ever been experienced before. Efficient performance of the work was assured by general policies and the high quality of the supervisory and job personnel. It was the writer's privilege to participate in this work as Head Construction Plant Engineer, in general charge of construction planning, plant and equipment design and selection, performance analysis, job cost engineering, and related research.

The nature of the work brought with it the obligation of properly accounting for the expenditures of large sums of public funds, and of making purchases of equipment in the best interests of the users and with fair consideration toward the manufacturers. This demanded a careful study of best prevailing construction practices, to which the private construction industry gave generous assistance, and critical analysis of all machinery and equipment with respect to design and performance. In time, a large variety of valuable records was assembled in the general field of construction planning and equipment.

Early in 1935 S. T. Henry, founder of *Construction Methods*, suggested that part of the records and experiences be published in that magazine as a series of ten articles. The assignment originally sounded simple. To this was added the desire to give the construction industry, which had helped in the gathering of the data, whatever benefits such publication might offer. The magnitude of the assignment was not fully appreciated, but with the generous help of R. K. Tomlin, editor of *Construction Methods*, and the encouragement from many readers, the series grew to twenty-six installments. During that period the writer had the benefit of Mr. Locher's advice and sound judgment in the preparation of the articles now forming this book, and his name has, therefore, appeared as co-author.

Other assistance and helpful suggestions came from many sides. Special credit is due a large number of the writer's former associates, including Robert T. Colburn, Frank T. Matthias, R. E. Karp, H. P. Maxton, P. H. Kline, W. I. Self, T. S. Whitehouse, George P. Jessup, Ross White, Miss Kathryn Hines, and others. Appreciation is extended to Arthur E. Morgan, then chairman and chief engineer, and Carl A. Bock, assistant chief engineer, on the T.V.A. projects for permission to describe and illustrate the many activities on these projects.

Among the many manufacturers of construction equipment who cooperated in the preparation of the articles and of this book by furnishing illustrations, technical data, or valuable suggestions are: Allis-Chalmers Manufacturing Co.; American Hoist & Derrick Co.; American Steel & Wire Co.; Austin-Western Road Machinery Co.; Bucyrus Erie Co.; Byron Jackson Co.; Caterpillar Tractor Co.; Fuller Company; Ingersoll Rand Company; Insley Mfg. Co.; C. S. Johnson Company; Koehring Company;

A. Leschen & Sons Co.; R. G. LeTourneau, Inc.; Kenneth F. Parks; Lidgerwood Mfg. Co.; Mack International Truck Corp.; Morris Machine Works; Moretrench Corp.; Northwest Engineering Co.; E. G. Robinson Co.; Sauerman Bros.; Sullivan Machinery Co.; Thew Shovel Co.; Union Iron Works; Vulcan Iron Works.

A number of engineering and construction firms, as well as the U.S. Engineer Department and the Bureau of Reclamation, furnished useful information. In many cases the authors drew on their experiences from other jobs; several times they went beyond their own experiences and drew from published records on still other jobs or from personal inspection of such jobs in order to round out the scope of the subject matter. This was done to provide a more useful reference for the student in heavy construction.

If this book succeeds, first, in offering a useful reference for the construction man and, second, in pointing out to what extent construction is an art capable of scientific analysis, the effort required to prepare it has been worth while. But, construction will always remain an art because to its science must be added the experience, ability, ingenuity, imagination, initiative, cooperative effort and courage of the practical builder. Every man from the waterboy to the president contributes his share in providing such qualities, and these do not come from "book-learning."

ADOLPH J. ACKERMAN.

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June, 1940.

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CHAPTER I

GENERAL PROBLEMS

Modern construction has, in general, developed into a process where plant layout and equipment are the primary factors in the execution of a job. New equipment has expanded the scope of such work to a point where it is now economically feasible to undertake projects which were only dreams a decade or two ago. Although in some cases the ideal plant layout may be an ingenious combination of standard machines and equipment, recent experiences have shown that new designs and developments of special plant features frequently pay for themselves on a single job even though their first cost appears high.

The remarkable achievements in this class of work are universally recognized; however a clearer understanding of some of its problems is of primary importance. Summarized below are some of those problems that have a vital bearing upon future developments and progress in this field.

1. *Gambling.*—In the heavier classes of work, experienced, competent, and conservative construction service is in general offered by a relatively small number of contractors. One need only look at recent bid sheets of major projects and observe bid variations of 50 to 100 per cent, to conclude that the job is considered a big gamble, a chance for a "killing," or that some bidders don't know what it's all about. Such factors destroy confidence and breed in the minds of owners or public officials an element of doubt regarding the ability of bidders, which the competent contractor frequently finds a major obstacle in his own progress.

2. *Inexperience.*—Because of lack of activity in their own specialized field, contractors frequently venture into other fields with an inadequate background and with no conception what-

ever of what constitutes proper planning and plant layout for such work.

3. *Financing.*—The problems of financing large construction contracts have frequently resulted in several contracting firms forming a partnership to bid a job, thereby introducing complications in reconciling opinions with respect to construction plant, programs, responsibility, and supervisory authority.

4. *Plant.*—Many contractors, particularly when handicapped by partnership difficulties and financial limitations, fail at the outset to recognize the importance of adequate advance expenditures for plant and facilities that will produce the lowest final cost of the job. It is difficult to sell a contractor a plant for $600,000, on which another $150,000 would cover all maintenance, repair, and lost-time expenses for the period of the job, as compared with selling him a $500,000 plant on which another $350,000 would go into such job expenses and extra labor. This is largely because such job expenses are not recognized in their true relationship except after first-hand experience.

5. *Equipment Selection.*—Proper equipment selection is entirely a matter of first-hand construction experience. Some manufacturers have done an admirable job in working hand in hand with constructors in defining equipment requirements and, particularly, in developing special equipment. Others, under the stress of competition, have gone the limit in selling their standard line (usually more profitable), and where unwary purchasers have blindly accepted the claims and recommendations of the seller the ultimate results have frequently been unhappy for both parties. Furthermore, progress in the construction art has thereby been retarded in a general way.

6. *Manufacturers.*—The competent and conscientious equipment manufacturer is a contractor's most important ally. Both are seeking—and are entitled to—a fair profit on their respective operations. Too often some equipment buyer delights in forcing the maker to knock off another 5 or 10 per cent, or he accepts a cheaper article, with the usual result that before the job is ended ten or twenty times the difference has trickled away. Burdensome policies of pricing and long-term financing on equipment purchases are considered by some contractors all right in one direction, but when similar ideas are proposed to them by their clients on their own work they usually protest with a great display of injured feeling. On the other hand, some

seller will occasionally volunteer distorted inducements just to get the order; this practice, obviously, is equally poor business. There is no substitute for good equipment; sound development in this field means greater progress in the construction industry as a whole.

7. *Engineers.*—Many engineers in their trend of thought and design are out of step with the art of construction. This applies not only to some designers of projects, but also to many engineers who attempt to sell their services to contractors. The complaint is often made that most engineers fail to think in terms of construction and, as a result, contractors have frequently attempted to get along without technical advice. Planning for construction involves a large amount of engineering, and competent and practical engineering service is a vital part of a modern contractor's organization.

8. *Risks.*—Most construction involves tremendous risks not only in physical damage during construction by floods, fire, breakdowns, weather, subsidence, and sabotage, but also in price changes in material, machinery, and labor markets. One old contractor was in the habit of calling his business a combination construction and insurance underwriting venture. In many cases the risk, or insurance phase, of a job runs high, and it is reasonable that the contractor be rewarded in proportion to the risks which the owner or public agency expects him to assume. This phase, however, is often abused either by an unfair attitude toward honest contractors or by a variety of dishonest practices on the part of unscrupulous contractors. Under the guise of adequate reward for heavy construction risks, political graft has entered into some large public projects. This may develop in the most unsuspected ways: Some time ago a reputable contractor was low bidder on a large public sewer job, but award of the contract was mysteriously withheld until he was approached by an individual who offered to sell him for $25,000 "expert advice" on how to secure the contract. The plot collapsed when the contractor publicly offered to increase his bond by 50 per cent to dispel any doubts regarding his ability to perform. Construction must be freed of any popular notions that it may tie in with graft or corruption; the building up of confidence is one of the most important phases of planning.

9. *Day Labor or Force Account Work.*—The competition from public agencies and others in doing their own construction is a

major obstacle to healthy development of the construction industry and deserves the intensive interest of all parties concerned to rectify this trend.

10. *Union Labor.*—In recent years organized labor has acquired new privileges and legal protection, and the industry is facing a transition in labor relations which presents some of the most fundamental problems ever encountered. Many contractors have discovered that where a sincere attempt is made to meet the legitimate and proper demands of workmen, the ultimate result is beneficial to both parties.

11. *Mechanization.*—The future of construction will depend largely on new developments in plant and procedure which will spell lower costs. The consequent increase in volume and extension of new frontiers in engineering development will benefit not merely the construction industry but also the country at large. The benefit of mechanization is not readily apparent, but expert economic surveys have established that during the past 60 years the installed horsepower in American factories increased 18.3 times. During the same period population increased 3.19 times, while the number of persons gainfully occupied increased 4.09 times. In other words, in spite of tremendous growth in installed power in factories during the past 60 years, the number of people gainfully employed has increased one-third faster than the population itself has increased. This evidence revealed by experience in the manufacturing industry can safely be applied to the construction industry.

It is hoped that this book will help to stimulate a greater appreciation of the achievements and vital importance of construction. The individual chapters cover special phases of its make-up. Although there are many specialized fields of construction which cannot be adequately covered in one book, most of the important construction operations are described by centering discussion upon large dam projects, with power and irrigation appurtenances, in order to provide some logical continuity and relationship. It should be emphasized that all the principles which apply to a big job, also apply to a small one. In fact, many large jobs are only a combination of smaller ones. By centering discussion on big jobs, the application of many principles is generally more obvious, and their application to smaller jobs with proper adjustment is a matter of judgment.

CHAPTER II

PRELIMINARY PLANNING

Most big jobs last from 2 to 4 years. The degree of success which attends such jobs is directly proportional to the ability which has been employed in accurately predicting the many conditions and contingencies which may develop over such a long period of time. From a contractor's standpoint, the two most critical periods of a job are, first, when he decides to bid a job and makes a detailed preliminary analysis, and, second, having been awarded the job, when he sets up his plant and thereby fixes once and for all most of the important construction procedures. We shall first discuss briefly the importance of preliminary studies which, in general, precede the filing of a bid or actual moving in on a job.

Number one rule is, obviously: *Study the specifications.* The very simplicity of this rule may invite indifference, but the word "study" is an extremely important one. It is impossible to write a perfect specification, and unless a contractor thoroughly understands their *intent* as to what he is to build and under what limitations, he can hardly make an intelligent analysis of how he is going to do the job.

The second rule is: *Study the job.* This means chiefly the physical conditions and related factors which have an important bearing upon construction procedure. Table 1 is a general "Check List" for the construction planner which indicates the many local factors, most or all of which he must analyze in planning a job.

Topography.—On a large dam project the topography of the site is one of the controlling factors in determining the construction procedure. A canyon site would in all probability call for a cableway layout, whereas a long low-head dam in a flat river valley would probably require a construction bridge and cranes. Topographic conditions will largely govern the location of suitable foundations for screening plant, mixer plant, cableways, access

roads, and miscellaneous plant buildings. In a flat valley these problems are generally not serious, but in a canyon site they may take on primary importance. Frequently it is possible to start

TABLE 1.—CHECK LIST FOR THE CONSTRUCTION PLANNER

TOPOGRAPHY	
Camp location	Spoil areas
Plant layout	Anchorages
Storage areas	Drainage

GEOLOGY	
Overburden	Stratification
Subsoil	Faults
Ground water	Physical character
Springs	Solution channels
Caves	
Rock	

CLIMATE	
Temperature	Ice
Seasons	Storms
Rainfall	Tornadoes
Snow	Earthquakes
Mud	Dust

RIVER STAGES	
Normal flow	Rating curves
Low water	Backwater
Floods	Stage predictions

PROPERTY	
Adjacent owners	Riparian rights
Boundaries	Mineral rights
Access	Timber rights
Purchase	Dumping rights
Rentals	Sanitary rights
Easements	Fire hazards

SHIPPING FACILITIES	
Rail and highway	Waterway
Tunnels—clearances	Locks
Bridges	Draft
Curves	Speed
Tariffs and fees	Return load
Transfers	Docks
Terminals	Loadings and unloading

POWER, FUEL, AND WATER	
Kinds	Transmission
Sources	Portable plants
Characteristics	Central plants
Capacities	Water supply
Rates	Storage

HOUSING FACILITIES	
Nearest town	Hospital
Camp	Schools
Sanitation	Fire and police
Food supply	Gardens
Water supply	

LABOR	
Regulations	Seasons: Variations
Wage scales	Local and imported
Compensation insurance	Skilled and unskilled
Availability	Race and color

PUBLIC RELATIONS	
Owners' policies	Local purchases
Political structure	Visitors
Local contracts	Public liability

COORDINATION OF DESIGN	
Possible changes	Sequence of work
Undefined work	Heavy installations
Extra work	Inspection

LOCAL CONDITIONS

There may be dozens of local conditions which the planner must consider, and this check list cannot be accepted as a complete guide.

a job by excavating for the foundation of the dam and spoiling the earth and rock into adjacent areas so as to develop a well-graded space on which construction-plant buildings can be erected.

Geology of Site.—A study of geological conditions at the site is of equal importance. Where manufactured aggregate is to be used, the selection of the most suitable quarry site definitely ties down the plant layout and defines one of the principal construction costs.

The records of foundation explorations and borings for the main dam should be carefully inspected, and it is important to know how they were obtained so that check calculations can be made of the different classes of excavations. An intelligent selection of the most suitable and economical excavating equipment cannot be made if there are possibilities of extended overruns or underruns in the different kinds of materials, such as earth and rock.

In general a dam is designed to use as far as possible the prevailing natural materials of the region. Before a constructor can adequately determine how these materials are to be handled he must know the nature and location of their deposits. Can the excavation from the dam be used for concrete aggregate? If earth dams are to be built, is the material sandy or full of clay? How will it handle? What kind of equipment should be used? In the case of rock for rock fills, how will it break? How will the equipment stand up? What size of equipment is needed? Over what kind of surfaces must it travel? These are only a few of the many questions which must be answered by a careful exploration of the site.

Climatic Conditions.—The effect of weather on construction is full of uncertainties and at the same time is one of the important factors in selecting the most suitable equipment for the job. Extensive rains may have an important bearing upon the selection of hauling equipment, such as trucks versus tractors. A job came up recently requiring about 2,000,000 yd. of rolled earth fill for a dam. This type of dam was selected because the natural deposit of material at the site was almost ideally suited for a rolled fill. However, upon further consideration of the rainfall conditions in the region, it became evident that the work might be repeatedly shut down because of the probability that excessive moisture would prevent proper rolling and compacting of the material. It was subsequently agreed to build a hydraulic fill dam and employ a dredge instead of rolling equipment. The results were highly satisfactory and shutdowns due to rains

were eliminated. In colder climates the technique of winter construction requires special consideration.

A large construction job which is up for consideration attracts contractors and builders from all parts of the country, and one or two of them may have seen the region and the site of the job for the first time. If the stage of the river at that time is used as a basis for sizing up the job, succeeding experiences may be very unhappy, as has been demonstrated time and again.

Labor Market.—There is the further study of the labor market. For this purpose it is very desirable to have the prospective superintendent in charge of construction available so that he may assist in analyzing labor conditions of the region, because this relates to one of his primary responsibilities throughout the period of construction. He will need a large number of skilled carpenters, especially at the beginning of the job, for building camp and other buildings. Mechanics will be in demand, as will common labor, and it is desirable to study what effects a large construction job will have upon present industries in the region. Wage rates must be carefully analyzed on a basis of fairness and with a view to maintaining a satisfactory stability of labor conditions in the region.

Housing Facilities.—The housing facilities near the site of the work must be studied to determine adequate accommodations for the first contingent of workers and in deciding on how much camp to build for supervisors and for such classes of workmen as are not obtainable from the region. A reasonable consideration of these factors can dispel considerable exploitation at the expense of the constructor's prospective employees. During construction it is important to maintain adequate policing and health service and to assist in preventing the growth of undesirable areas of "squatters" in the vicinity of the job.

Public Relations.—When a constructor is about to enter a new region a cooperative spirit toward community officials and civic leaders of the region is not only essential for maintaining a reasonable stability for the residents of the region, but he will also materially benefit his own work and his own personnel if he enjoys their good will. A contractor on a big job immediately becomes a very influential factor in the region by virtue of the large expenditures which he makes. If he starts right by dealing with local markets for small requirements, helps with civic

problems, and displays a spirit of fair dealing in the use of local labor, he is building up a definite source of profitable return. Such local support may at times keep him out of serious legal entanglements. Recently an out-of-town contractor needed a large storage space along a river for bringing in his sand and gravel only to find that all the most suitable sites had been optioned by a competitor, who, having failed to land the job, still expected to clean up by selling his option to the successful bidder. It so happened that the city owned a satisfactory site and by cooperatively working out a plan for employing local labor, making local purchases and assisting with other community benefits, the contractor won the good will of the local people and obtained the site at a very moderate cost.

A builder's responsibility is not only limited to the period of construction but extends many years into the future. There is much to be gained in leaving behind a good reputation, which, in the long run, is bound to pay big returns. Every large project creates a new monument of permanent value to the region, and, instead of temporarily creating a boom town which is left behind entirely dead and in a lifeless region, the members of the community should have gained, and are entitled to, a better state of living and citizenship.

Analysis of Plant Layout.—The subject of plant layout will be discussed in considerable detail in succeeding chapters. However, as part of a preliminary study of a project, it is important that all the primary factors which go to make up a plant layout are recognized in their true relationship. As already stated, the site and natural topography definitely determine certain types of plants, whether they be of the type involving transportation by air, such as cableways, or on ground, or on water (Fig. 1). This sketch illustrates an important principle of plant layout. Lowering is cheaper and faster than hoisting when placing concrete in a dam. Where topography requires the quarry and aggregates storage to be located at approximately normal river level it is generally better to elevate the raw materials by belt conveyor to an upper mixing plant so located as to permit delivery of concrete to the dam somewhere within the upper half of its total height.

As a rule, the materials-handling or hoisting equipment is required to perform a large variety of functions in building a

dam, and the selected layout must be able to do all that is required of it. For example, in recent years five dams, similar in size, setting, and general characteristics from a construction standpoint, were completed, yet the builders chose distinctly different methods and equipment. The Pardee Dam was built with a central tower elevator and chutes; the Ariel Dam by means of whirler cranes; Santeetlah Dam with guy derricks; Diablo Dam

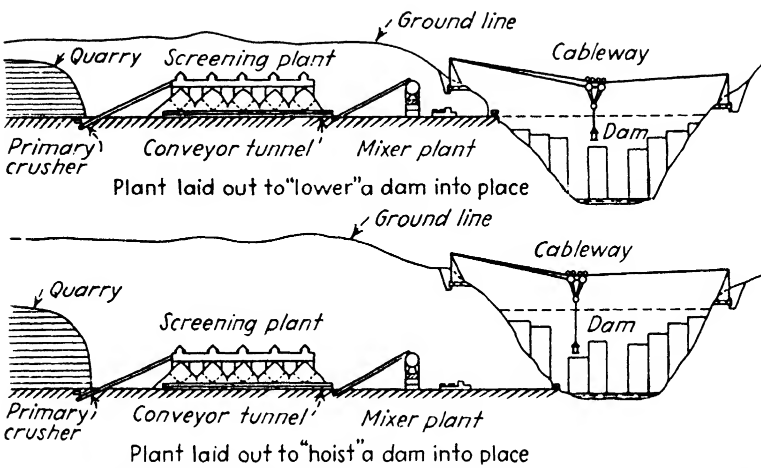


FIG. 1.—Diagram showing principle of "hoisting" and "lowering" a dam into place.

by means of two high elevator towers with belt conveyor booms; and Madden Dam by means of a cableway. It is the responsibility of the construction planner to determine by engineering analysis which is the most economical and best method for a given job.

The size of the plant is of primary importance, and although there would be a natural tendency to underplant a job, particularly where a contractor is required to buy all new equipment, there is a very definite danger of overplanting a job where a contractor has standing idle a large amount of used equipment which he feels should all be earning money for him. Every job has a certain "best rate" of production. Either a slower or a faster schedule means higher costs and reduced profits. Certain requirements of the specifications may also affect the rate, and, at the same time, progress of the work must tie in generally with

the river stages during construction, with proper regard for flood seasons.

Power supply, source of fresh water, source of raw water for concrete mixing, and similar factors require proper analysis.

As a general rule, it is possible to make comparisons with current or previous similar projects as a guide for analyzing a new site. Such elements as excavating procedure, concrete handling, dredging, or making sand from rock require careful consideration in the light of past experience. At the same time, every job demands painstaking study of all proposed operations in order to determine how to do the required work for the least expenditure of money. The remarkable construction record made on Hoover Dam emphasizes the high degree of vision and skill employed in correctly analyzing a difficult job of unprecedented magnitude and in developing an equipment and plant layout in terms of size and output which, up to that time, were entirely unknown.

In laying out a plant, many principles which are discussed in detail in succeeding chapters must be considered. However, as a general thing it is desirable to make a layout which, as the work goes on, tends to systematize itself. It is a very expensive job to teach 2,000 to 4,000 men how to keep their work going in the most economical manner for the project as a whole. Where the equipment functions so as to permit everyone to become familiar with its purposes, there is a natural "catching on" on the part of every man on the job, which helps to keep the ball rolling. As a rule, the first cost of a plant is a relatively small element of the total cost of doing the job. The day-to-day costs are what count, and where these can be reduced by a more expensive plant, within reasonable limits, such opportunities should not be overlooked.

Once the plant is designed and built, the entire job is practically fixed. If the plant is right, the job is as good as done. If wrong, it costs more to change, as a general rule, than can be saved. Errors in any selection of plant or equipment not only retard construction progress in general but also lower the morale on the entire job.

One important principle that will be stated here at the outset and may not occur frequently enough hereafter to keep its importance in the mind of the reader is this: special equipment

is an essential part of heavy construction, but on every individual job there are opportunities for employing standard equipment or even hand labor for maximum economy. Careful planning and experienced judgment will keep these methods in proper balance.

Models of Construction Layout and Equipment.—Frequently a small model of a device or of a plant layout will serve as a valuable check of a paper study, or will often bring out elements that have previously been overlooked. Such questions as river handling and cofferdam problems require a thorough analysis of step-by-step procedure, and if these steps are first carried out on models, many potential mistakes will be disclosed and prevented on the full-scale work. Similarly, models of special pieces of equipment will provide valuable information and, in any case, reassurance before any large expenditures are made on full-scale operation that the proposed scheme will work satisfactorily.

On a recent job there was a rather difficult piece of excavation work required within a constricted cofferdam area. The excavating and hauling equipment had certain limitations of reach and maneuverability. It was necessary first to uncover certain foundation areas so as to permit concreting to start without further delay. At the same time, it was necessary to maintain ramps around the exposed foundations so that, as the excavation went down, there was always an opportunity to get out with the hauling equipment and finally with the excavators and shovels. By building a model of the cofferdam area and using sand to represent the required excavation material, three or four different proposed methods were studied, but the most satisfactory one was a new one which was developed on this model. By bringing in the foremen and shovel operators and showing them the intended procedure, every one understood thoroughly what was proposed, and the cost of the model was saved many times over.

At Norris Dam, artificial aggregate and requirements for a relatively dry mix called for concrete which was rather difficult to handle in large batches with standard commercial concrete buckets, particularly for service on cableways. A full bottom discharge opening was required, and at the same time it was essential to discharge the concrete without excessive rebound

of the cableway. Various special buckets were designed and the best type was finally built on a small scale and tried out. This disclosed a number of points which required improvement and was a big help in arriving at a satisfactory solution of the problem. Further improvements were made under actual operating conditions and resulted in a very satisfactory type of bucket.

Coordinating Design and Selection of Plant.—A great deal of money can be saved if the builder and the engineer become acquainted with each other during the early stages of the job planning. Specification requirements can frequently be cleared up so as to save the builder a lot of unnecessary worry. The construction man, as a rule, also has some valuable experiences to contribute to the job, and if these are properly worked out with the engineer, the results may be a more satisfactory piece of work for the owner and considerably less difficulties for the builder. Some of the more common questions which occur on practically every job are: The height of lift in concrete placement, and location of construction joints; substituting laps for unnecessarily long reinforcing bars which seriously interfere with handling of concrete; boxing out for gate guides and similar structural steel which can be more satisfactorily installed after the heavy part of the structure is completed; permissible changes in sequence of starting various sections of the work can often lead to important economies.

Summary.—To summarize, if the preliminary studies have been carried out in a thorough manner the builder can determine his costs with greater confidence, and ultimate success is envisioned more distinctly right from the start. Furthermore, he can proceed with a well-defined plan the day he is notified and may gain a season of construction, beat the floods or rains, or have everything in readiness when the most opportune starting time breaks.

CHAPTER III

PREPARATORY WORK—ACCESS TO JOB—CAMP BUILDINGS

Starting the Job.—"Don't start too soon is just as important as the warning "Don't get caught with a late start." When the advance guard gets on the job the overhead starts. Planning the start means to find out when enough operations are lined up to keep the job going without a hitch and at the same time justify the ever-present overhead expense. If the starting date is set to take full advantage of favorable conditions, and definite commitments are made as to arrival dates of construction plant and personnel, and if the key foremen are all familiar with the general program, the job can get started with a "bang."

What this means is best illustrated by the following piece of bunkhouse gossip between two shovel operators: "Tom, this is going to be a real job. The old man sure knows what he's doing. We've been here only two days and he's lined up boarding places, one bunkhouse is finished and the cookhouse is running. The shovels were waiting for us at the railroad siding, and as soon as we get the road cut finished he'll have enough clearing done at the dam to start stripping the dirt off the rock. The air compressor arrives tomorrow and by the time it's set up the power line will be in and we should be ready to start on the rock."

"Yeah, what difference from old man Evans' job last year. He told us to be in Elkmont on March 10 to take the shovels off the flat cars and when we got there he had found out that they wouldn't go through one of the tunnels, so he had to ship them all the way around. On top of that, he left the spare parts behind and the first day of work a gear broke so we had to wait for a new one. When we got started at the dam he didn't have enough men to keep ahead on the clearing and we only ran the shovels one shift. The first bunkhouse wasn't ready for three weeks and I didn't have a square meal for a month. We never got going on that job."

Access Roads.—Until a few years ago most construction superintendents thought only in terms of railroads in considering means of access to the site. On certain projects this may still be the most economical system, but the modern heavy-duty highway equipment and special trailers with capacities of 100 tons or more can meet practically every job demand. Cement, which is usually considered the major item of traffic for a large dam, can be hauled economically over the highways, in some cases over distances ranging up to 40 or 50 miles depending upon near-by railroad facilities and topography of the region. In remote cases hauling distances may be many times greater.

The construction of access highways, when of considerable length, can generally be handled most economically under a subcontract by a specialist in this class of work. However, on short stretches and in remote regions it is frequently possible to select equipment which may later fit into the main job and, although not the most efficient for the immediate purpose, the entire operation may be the cheaper in the long run. In almost every case a large job has a number of smaller appurtenant works which are not located within reach of the main construction plant. For these smaller jobs the more portable pieces of highway-construction equipment, such as small gravel or crushing plants, grading equipment, portable air compressors, cement-handling equipment, mixing units, etc., frequently offer an ideal plant setup for a variety of odd jobs.

Layout of Construction Camp.—Depending upon the duration and size of the job, considerable effort is warranted in carefully laying out the camp site. Table 2 gives a list of various facilities found in a large camp and some of these go into every camp. An example of what can be done along these lines is given in Fig. 2 showing the camp at Pickwick Landing Dam in Tennessee. By curving the streets to fit topography and shade trees and spacing the homes reasonably far apart, every inducement is offered to the tenant to help take care of his lot and contribute to the landscaping of the area. Some general principles to be observed in the relative location of the various types of buildings are the following:

The bunkhouses and dining hall should be grouped into one area where the unmarried personnel have reasonable privacy and a minimum of disturbance for those sleeping during the

TABLE 2.—TYPICAL CONSTRUCTION-CAMP FACILITIES

Type of building	General features	Purpose	Dimensions of typical buildings	Cost of typical units	Representative list of installed equipment and facilities
Permanent houses	Average-size permanent houses with all modern facilities	Housing for job officials and resident operators	Seven rooms 44 × 60 ft.; 5 to 15 required	$6,000	Standard home equipment; refrigerator, heating system, etc.
Temporary cottages	Small houses; compact, portable or demountable; low cost; temporary construction	Housing of married supervisory staff and skilled personnel	Five rooms 22 by 27 ft.; seven rooms 22 by 36 ft.; 50 to 200 required	$1,000 to $1,500	Bathroom fixtures; kitchen plumbing; lighting; heating, etc.
Dormitories	Rooms about 9 by 10 ft.; corridors; special exits; vestibules; special windows; linen room; toilets; two men per room	Housing of labor	180 by 25 ft. (two wings), 40 rooms in each; 44 by 22 ft. wash room. Three to seven required	$100 to $150 per man	Washbasins; toilets; showers and dry room; hot-water tank; heating system Each room: beds, tables, chairs, lights, closets
Staff house	Rooms about 10 by 14 ft.; lobby; shower baths; etc.	Housing of foremen, engineers, office men	140 by 25 ft.; one required	$250 per man; $7,000	Same as in dormitories, but better quality covered by higher rentals
Girls' dormitory	Rooms about 10 by 14 ft.; lobby; water supply, etc.	Housing for teachers, stenographers, clerical ladies	70 by 25 ft., one required	$4,000	Same as for staff house
Dining hall, kitchen, and bake shop	Large hall; special exits; kitchen; preparation room; storage for meats, vegetables, etc.	Feeding laborers and other workers	140 by 45 ft. for 300 seats; one or two required	$20,000 with equipment	Dishwasher; floor-scrubbing machine; electric griddles; coffee urns; ranges; potato peelers; steamers; refrigerator; slicing machine, bake ovens; meat grinder; dough mixer; cake mixer; utensil racks, etc.
Guest house or hotel	Small building, 10 or more rooms, with running water and other hotel features	Quarters for transients, visiting officials, etc.	70 by 25 ft., one required	$5,000	Same as in dormitories or typical hotel accommodations

Community hall	Auditorium; community area and recreational facilities; library and miscellaneous rooms; toilets	General service and recreational facilities for the workmen and families	Auditorium 88 by 44 ft.; reading and classrooms, 36 by 99 ft.; recreational area, 98 by 40 ft., one required	$35,000	Projection booth; lounge furniture; post office; barber shop; billiard room; offices; soda counter; library; games
School	Classrooms; office; toilets; play areas	Educational facilities for workers' children	100 by 80 ft. plus playground area; one required	$9,000	Classroom—furniture; toilet fixtures—water fountain; playground equipment
Church	Community church in large camps where other buildings are not suitable	Church activities for workers and natives of region	One required		Benches; pulpit; altar; other church equipment
Town office, police, and fire department	Office building and garage annex for fire truck	Office for camp manager, police headquarters, space for fire truck, etc.	One required	$4,000	Office equipment; alarm equipment; vault; hose and chemical truck
Hospital	Waiting room; offices; examination room; laboratories; toilets and baths; wards (white, colored, male, and female); private rooms; delivery room; medicine room; stores and linens; X-ray room; supplies for surgical wards; surgery room; porches; ambulance entrance; resident doctors' living room; kitchen	Examination of applicants, care of injured, and community needs; operations, disease control, sanitation	106 by 32 ft. 6 in.; 57 by 36 ft. wing; one required	$20,000	Operating table; X-ray equipment; baths and toilets; kitchen equipment; beds; office furniture; signal system; surgical supplies and instruments; dental equipment
Commissaries and store	Typical store building for groceries and meats; dry goods and clothing; drugs and soda	Trading center	100 by 45 ft.; one required	$10,000 with equipment	Shelves; counters; soda fountain; meat counters; cold storage; miscellaneous store fixtures
Laundry	Simple building arranged for laundry equipment	Cleaning dormitory and dining hall linens, etc.	44 by 22 ft.; one required	$5,000 with equipment	Washing machine; mangles; ironers; wringers; tubs; baskets; driers, etc.
Garage, repair shop, and filling station	Car-repair building, concrete floor; open pit; large doors	Servicing and repairing employees' and transients' automobiles	40 by 70 ft., one required	$7,000	Wrecking car; chain falls; automobile rack; gasoline pump; oil tanks; gasoline tanks; air compressor; tools; benches; parts storage

daytime. The school, stores, community building, and other facilities should be grouped, in so far as possible, to be most conveniently accessible to all inhabitants of the camp without crossing traffic lanes unnecessarily. The hospital should be located with due consideration to quietness, good air circulation, and quick access from the job to take care of emergency cases

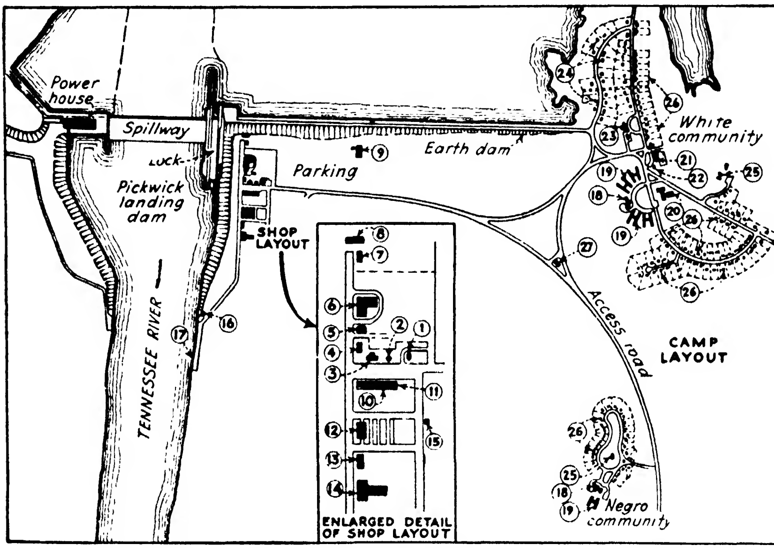


FIG. 2.—Construction camp and shop layout at Pickwick Landing Dam in Tennessee. Camp site is in wooded area above high water and shops are adjacent to construction operations.

Shop Layout: (1) First-aid station. (2) Lunch room. (3) Time office. (4) Small tool house. (5) Garage repair shop. (6) Machine and blacksmith shop. (7) Electricians' shop. (8) Compressor house. (9) Switch house and substation. (10) Warehouse. (11) Riggers' shop. (12) Office. (13) Testing laboratory. (14) Carpenter shop. (15) Reinforcing yard office. (16) Derrick-barge landing. (17) Ferry landing.

Camp Layout: (18) Cafeteria. (19) Dormitories. (20) Community building. (21) Store. (22) Fire station and camp manager's office. (23) Hospital. (24) Permanent houses for operators. (25) School. (26) Workmen's cottages. (27) Filling station.

with a minimum loss of time. The Pickwick camp can accommodate 550 men in the dormitories and 100 families in 85 temporary cottages and 15 permanent houses. A separate small village for colored employees is provided with one 150-man dormitory, 25 family cottages and a separate school, commissary, and small recreational building. The proportions of these facilities were determined from a careful analysis of nearby communities, labor markets, and type and quantity of skilled and supervisory personnel required for the construction program.

It is frequently the case that a large portion of the camp installation can be more economically accomplished by subcontract for the reason that small local contractors in the building line are thoroughly equipped with skilled labor, all necessary tools, and definite information as to just where necessary building materials can be obtained at proper costs and with no delay in delivery to the site.

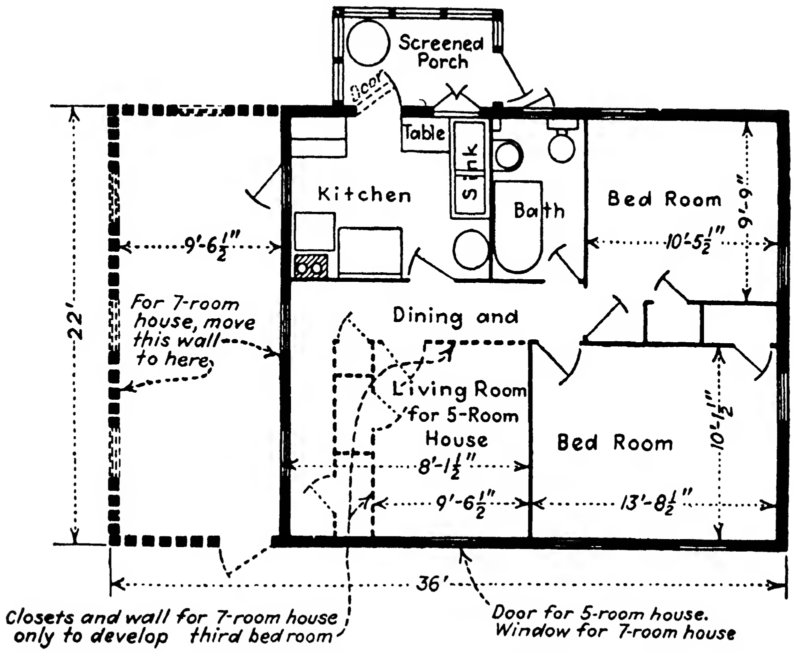


FIG. 3.—Floor plan of construction camp house (5 or 7 rooms).

As a general thing, a certain number of permanent houses are required for the operators and other personnel after the job is completed. At Pickwick these houses were built at the beginning of the job to serve temporarily as quarters for construction officials, and their location was determined in the general scheme of the village so as ultimately to front on the lake which was formed after the dam was completed.

Where such permanent houses are used during construction by the job officials, there is, of course, the possibility of inconvenience during the transition period when the operating force is ready to go to work before the construction organization is

ready to disband. Sometimes this period may be quite long. Furthermore, it is likely that the houses may require some reconditioning after 2 or 3 years' use by construction forces.

Temporary Houses.—In the construction of temporary houses large economies are possible in standardizing the floor plan without sacrificing variety in external appearance. By turning the houses in various directions and modifying the type and location of porches and other simple exterior effects, a pleasing result can be obtained at little extra cost.

A suitable type of cottage for construction camps is indicated in Fig. 3 showing a five-room house approximately 22 by 27 ft., containing two bedrooms, kitchen, bath, and living room with a dining corner. The plumbing is arranged compactly in adjoining kitchen and bathroom. All these details can be retained and the cottage enlarged to seven rooms to develop one additional bedroom and a dining room in a building 22 by 36 ft. for larger families.

In the case of widely scattered jobs involving the construction of long tunnels it is frequently necessary to establish subcamps near the portals and with them must, of course, go all necessary utilities and other facilities.

Dormitories.—The housing of large groups of men on major construction projects has undergone marked improvement during the past decade. The bunkhouse of older days was generally regarded as a temporary structure with only a few years of service and was, therefore, erected with a minimum of necessary facilities. As a general thing such bunkhouses consisted merely of walls, floor, and roof enclosing a considerable area and equipped with long rows of double-deck beds. Sleeping conditions were not so bad in summer, with all windows open, but when winter came along it was no easy matter to obtain a unanimous vote to keep the windows open during the night while a lone stove at the center of the room was attempting to radiate its heat to all parts. The circle of soggy boots and heavy socks carefully stacked around the stove for drying over night didn't exactly help the ventilating situation. In those days an expenditure of $100 per man for living quarters was considered high.

The more recent large-scale construction projects have required a more permanent type of structure with better facilities, for

which the name "dormitory" is quite appropriate. Today there is a greater realization of the fact that if the men are permitted to lead a more contented and better balanced life *off* the job their efficiency is bound to be greater *on* the job.

It was at one time common practice to make bunkhouses self-liquidating, and, of course, this required the cheapest kind of construction. More recently, however, the attitude is that increased expenditures for good living quarters can be repaid through greater output and efficiency on the job. A mechanic who has been connected with a construction job for two years has probably earned $3,000. Even a 5 per cent reduction in his efficiency would mean a loss of $150 to the contractor. Other things being equal, it is not difficult to visualize an improvement of 5 to 15 per cent in a man's efficiency over his "indifferent" rate of output, provided his habits of living off the job are such as to keep him in a healthy state of mind.

In modern camps an expenditure of $200 per man is not considered excessive, and this sum easily provides for individual rooms, or at least separate rooms for every two men. Improved heating facilities in the winter and air-conditioned ventilating systems for the summer are of extreme importance in providing adequate sleep and rest so that a man returns to the job fully refreshed for another day's work.

In some camps the dormitories are sufficiently large to house 100 to 150 men per building, while in other camps they are kept down to a capacity of 30 to 40 men. This depends to a great extent upon local conditions, arrangement of washroom facilities, fire hazards, and segregation of groups of men by shifts so that men sleeping during the daytime are not disturbed by the usual traffic and noise of the rest of the men. Figure 4 shows the general plan for a single-story dormitory designed to eliminate the overhead noises and greater fire hazard which generally are present in a two-story building.

It is important to recognize the principle that a man desires and is entitled to live in accordance with the established standards of a home. A recent trip through a modern bunkhouse disclosed the following: An electrician in the privacy of his room surrounded by high-grade books and so-called high-brow periodicals which to him were a source of considerable satisfaction and diversion; here and there mechanics and carpenters studying

blueprints and improving their ability to read them; a carpenter building a small model of the dam on which he was employed; in another room a mechanic making a paperweight and carving on it an outline of the dam; in other rooms a considerable number reading magazines or books for pastime and restfulness while a game or two of cards held forth in other rooms without disturbing the rest of the occupants of the dormitory. Needless to say, the job was going well.

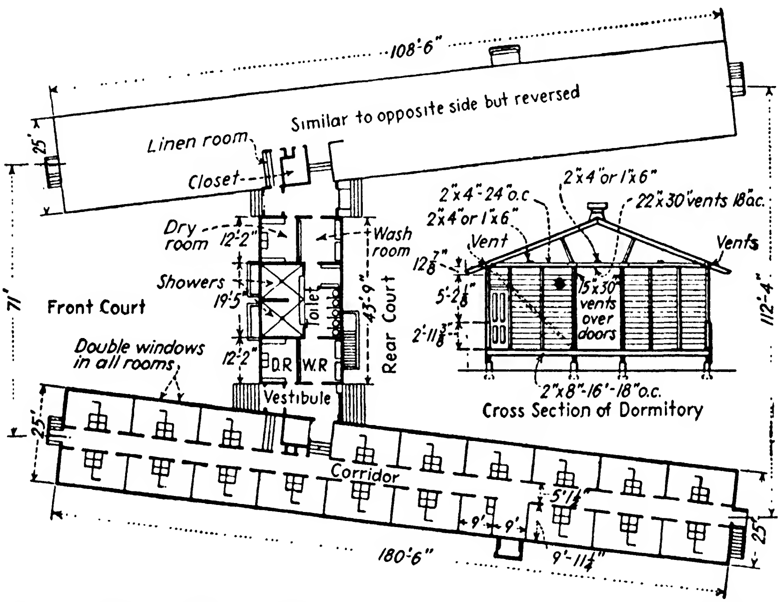


FIG. 4.—General design of large single-story dormitory for 150 men at 2 men per room.

Heating System.—In a number of camps recently constructed older forms of heating systems have been displaced by electric heaters. Special heaters are now on the market with which even large auditoriums can be successfully heated. In dormitories such heaters are particularly satisfactory because they permit control of temperature in individual rooms, are fireproof, and have a considerably higher salvage value than do other forms of heating in the size required for this type of camp structure.

Quarters for Engineers and Foremen.—A "staff" house is necessary on a large construction job, with individual rooms for

engineers, office men, and foremen, and usually with some additional facilities for carrying on their spare-time interests and doing a certain amount of planning of their work. This group is accustomed to good living facilities, for which they are willing to pay a higher rental, and to more expensive meals of a type consistent with the needs of office personnel and those engaged in less strenuous physical activities.

Dining Hall.—A modern construction job probably depends on no single camp feature more than upon the dining hall or mess hall. No matter how rough the day's work, with driving rain, blistering heat or wintry cold, the average construction man is not disposed to complain as long as he can sit down to three square meals a day. But let the standard of the meals go down and develop into a frequent repetition of pork, watery potatoes, thick gravy, and prunes or some stronger laxative dessert, and things can go pretty bad. For this reason it has been generally recognized that a kitchen and mess hall should contain all the most modern facilities, high standards of sanitation, refrigeration of perishable foods and last, but not least, a first-class staff of chefs and cooks.

At Norris, Wheeler, and Pickwick Landing dams a cafeteria type of dining hall was constructed, and this system has operated reasonably successfully. On Western projects direct table service is almost universally employed. Both systems have their merits; selection depends largely upon local conditions and individual preferences. Considerable judgment is required in determining the proper size of a dining hall. At Pickwick Landing the dining hall was designed for 300 men. On larger jobs, such as Conowingo and Grand Coulee, the dining halls had seats for 1,000 men. The size of a dining hall should not be overestimated, as it is generally found that staggering of shifts will materially reduce the peak demand. Ample ventilation, both natural and forced draft, adequate entrance and exit facilities, and sufficient space to carry on all operations of preparing the foods are standard requirements. A rather common accessory to the dining hall and kitchen is an ice-manufacturing plant, unless cold storage of food and all community requirements are taken care of by mechanical refrigeration.

Operating a mess hall is not the same as operating a modern hotel or city restaurant. Construction-camp operations are

highly specialized and require a thorough understanding of the average construction man's philosophy. As a result specialized operators for commissaries and construction camps can be engaged for individual projects. Exploitations and dangers to the tranquillity of the job are generally kept under control voluntarily by high-grade camp operators. The contractor usually protects himself by stipulating that for good cause such camp management services may be cancelled within 24 hr. Quite frequently the camp management staff is part of the construction organization, with equally satisfactory results.

A thorough understanding of what constitutes satisfactory camp facilities is frequently not recognized, as occurred some time ago on a small contract which justified but little expense for camp installation. In this case a timekeeper, who was a rather resourceful individual, was told that if he cared to take over the camp as a side issue, furnish food properly cooked and look after the management, any profit resulting therefrom would revert to him. In a few days there was a general uproar in the camp, and the contractor received a report that the new camp manager had peculiar ideas about cooking everything at one time in one kettle, then beating on an old tin pan and calling, "Come and get it." When approached about these conditions, the camp manager registered surprise over the prevailing dissatisfaction. He assured the contractor that he would keep affairs straight and well in hand—just leave everything to him. He explained that he had been to Chicago the day before, had stopped at the new Great Northern Hotel, one of the finest in the city, and that the guests there were all complaining about the food, too.

A camp manager's responsibility not only includes the housing and feeding of personnel, but also the purchasing of foods and other supplies in large quantities; controlling sanitation, refuse disposal, camp cleanup, and maintenance; and operation of a laundry, bake shop, incinerator, fumigating plant, and similar facilities. On a large project the personnel for these operations runs from 50 to 100 men. The rentals generally are required to cover operating charges and equipment plus as much of the cost of buildings as is reasonable and consistent with the workers' ability to pay. Operating costs of dormitories range from 10 to 15 cts. per man-night. The operation of a large kitchen and

dining hall for 24 hr. a day requires from 25 to 50 men on a large project.

Commissaries.—Every camp requires the operation of a store for dry goods, groceries, drugs, hardware, furniture, etc., and other commercial operations such as filling stations, transportation services to nearby towns, laundry, garage and repair service for employees' automobiles, bank, post office, etc. As long as such operations are handled by the contractor or by a concessionaire in such a manner as to satisfy the camp residents that they are getting a fair return for their money, the results will be reasonably satisfactory.

Entertainment.—The provision of adequate entertainment facilities is even more important in a construction camp than it is in more diversified city life. This is chiefly because a large group of people are thrown together who see each other day in and day out for several years, and the job can suffer a considerable financial loss if the residents of the camp are permitted to devote all their spare time to gossip and the formation of cliques and "mutual admiration societies."

A well-organized program of entertainment and recreation in the camp is a good investment. The families of job officials can render valuable assistance along these lines, particularly if they have the ability to avoid the appearance of "running the whole show." For purposes of entertainment a first-class community building is desirable. It should include an auditorium for motion pictures and lectures; playrooms for billiards and cards; a library; several small rooms for group meetings or educational classes; and a refreshment stand, post office, and similar facilities.

Other Camp Buildings.—Other standard facilities of a large construction camp include a town office for administrative, police, and fire-protection headquarters, a school and church, and a first-class hospital.

The hospital deserves special attention. A rather common expression in the heavy construction industry is that one life is lost for every million dollars cost of the project. Frequently an extremely hazardous operation brings with it a much higher mortality rate. Under some compensation laws a life is valued at $20,000. Considering for the moment cold cash figures, if only one or two lives are saved as the result of having a first-

class hospital, equipped to take care of practically any job contingency, the investment is worth while.

Sometimes the most desirable location for a hospital is at some distance from the center of construction operations. In such cases it is essential to erect a small first-aid station very near the center of operations, with a competent medical officer in attendance at all times to take care of emergency cases within a few moments after an accident has occurred.

Community Utilities.—A large construction camp is just like any other small town in requiring the usual utilities, such as streets properly graded and with gutters, paths for pedestrians, electric supply system, and telephones at least in the homes of construction officials and key foremen. The water supply consists generally of suitable wells, filtration plant, a water tank of ample capacity to meet the needs of the community and at the same time to take care of extinguishing a fire of considerable proportions, and fire hydrants properly spaced. The entire underground system must be carefully mapped so that it can be relocated readily in case of repairs. An adequate sewage disposal system is required as a sanitary measure with an economical type of Imhoff tank and drying bed or other system of disposal. On a recent privately built large job with a camp housing 1,500 men the water-supply system consisted of a filter plant with a capacity of 150 gal. per min. The water tank stored 100,000 gal., and peak demands on the system reached 200 gal. against an over-all average demand of 80 gal. per min. The entire fresh-water system for the community and raw-water system for construction operations cost $120,000, and the sewage system came to $55,000.

Finally, with the entire camp erected, reasonable consideration should be given to sodding the area, providing some shrubs, fencing, entrance gateways, and similar landscaping features which go a long way in encouraging a healthy community spirit.

Future of Construction Camps.—In urging upon constructors the provision of more livable camp and dormitory facilities it is desirable to point out that the construction industry and individual contractors should not be held responsible for all the past objectionable camp conditions. The majority of contractors on a large project would be very happy indeed to provide the best possible accommodations for their men by spending from

$100,000 to $300,000 of additional money on camps, but under competitive bidding this may be just the amount by which the job may be lost. The real responsibility rests with the agency for which the project is being constructed. Just as the completed project will change the economic balance and population of the region, to which, incidentally, a great deal of planning is devoted, so the same agency should also assume responsibility for adequately planning for the emergencies which arise from suddenly imposing upon the region a new community during the period of construction.

It would seem quite feasible for such agencies to include in their designs and specifications for the main project suitable designs and specifications for dormitories, dining halls, cottages, houses, and other community facilities so that all bidders could prepare their figures on the same basis. If such figures were filed as unit prices per building, the agency would be in a position to meet growing demands upon the community by ordering additional facilities constructed at the unit bid prices and retain a better position to combat the development of parasite communities with their attendant unsanitary and disease-promoting conditions, for which the occupants of such communities are least responsible.

CHAPTER IV

PREPARATORY WORK—SHOP BUILDINGS AND UTILITIES

Service Plant and Shops.—The general service-plant area, consisting of storage space, warehouses, shops, offices, and other yards, deserves a great deal of study in determining the most effective layout. Where it is possible to centralize all buildings, much can be accomplished in coordinating the flow of materials, equipment, and labor from the outside to the service plant and into the construction job. Study of the layout of the Pickwick plant (see Fig. 2) indicates that the approach road first passes through a parking area where employees may leave their cars, then runs past the time office where the men check in, from which they enter the small tool shed and pick up their tools. From there they go to the garage, machine shop, or electrician's shop and on to the work. Materials coming in are readily delivered to one of the shops or directly to the warehouse. The compressor building is located as nearly central to the work area as possible, convenient both to shops and to construction area, and the office and testing laboratory are located at some distance from the compressor plant and other noisy operations, but still convenient to all operations. Most of the lumber will arrive by water at a ferry landing, from where it will be handled by derrick to unloading docks into a lumberyard and from the lumberyard into the carpenter shop; from here built-up forms are delivered to the construction area. Here again the straight-line sequence of operations is evidenced.

Additional smaller buildings of the portable type are needed around a large job for headquarters of assistant superintendents and engineering layout crews.

Shop Buildings.—The general requirements of service-plant facilities and buildings for a large job, together with equipment, are presented in Table 3. For smaller jobs many of these units can be combined to reduce their cost. As a rule buildings are

of simple construction, consisting of wood frames and corrugated siding and roofing, except such buildings as the office, tool house, and electricians' shop, etc., where wood sheathing on the walls is desirable or convenient for attaching shelves and other facili-

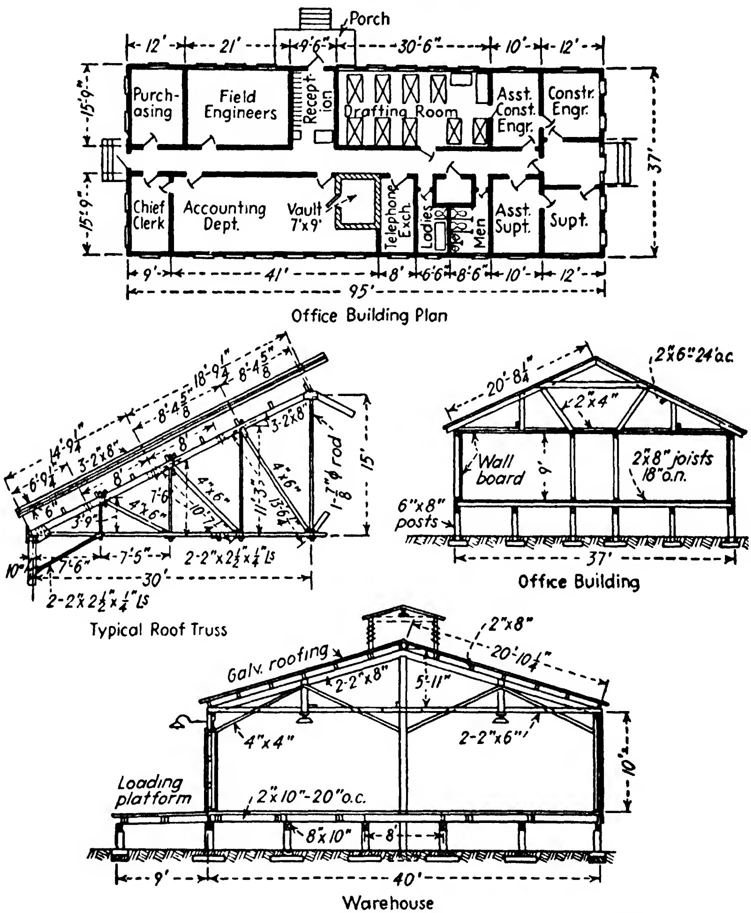


FIG. 5.—Typical designs of temporary construction plant buildings, including plan of office building, section of office building, section of warehouse, and typical design of roof truss with span of 60 ft.

ties. Typical construction as indicated in Fig. 5 consists of timber mud sills, 8- by 8-in. posts, 2- by 8-in. joists, 2- by 8-in. flooring, 1- by 12-in. vertical siding with 1- by 3-in. stripping, or corrugated iron, 2- by 6-in. rafters, 2 ft. on centers, 1- by 8-in. sheathing and metal or 3-ply slate roofing. In some cases

TABLE 3.—TYPICAL CONSTRUCTION-SHOP AND YARD FACILITIES

Type of building	General features	Purpose	Dimensions of typical buildings	Cost of typical units	Representative list of installed equipment and facilities
Main office	One or two-story; special windows and lighting, fireproof vault, exterior, siding; interior, composition board	Offices for superintendent, engineers, chief clerk, accountants and purchasing agent; also drafting and conference rooms	115 by 37 ft., 9-ft. ceiling	$11,000; 20 cts. per cu. ft.	Office and drafting furniture; reception desk; telephone switchboard; 2 toilets; built-in vault; high-grade illumination; drinking fountain; fire extinguishers; supply closet; heaters
Time office	One-story; office space; "in" and "out" check windows	Offices for paymaster, timekeepers, and payroll clerks	40 by 25 ft.	$2,800; 26 cts. per cu. ft.	Office furniture; employee check racks; adding machines; files; toilets; heaters
Employment office	One-story; office space; reception room; toilets	Offices for handling applications, interviewing applicants, and adjusting employment problems	40 by 25 ft.	$2,800	Office furniture; files; toilets; waiting-room benches; drinking fountains; heaters
Field engineers' suboffices	Plain building, but with good windows and lighting; office space	Headquarters for field engineers; surveying instruments and supplies	40 by 20 ft.	$2,000	Office furniture; instrument racks; lockers; heaters; shelves; benches
First-aid building	Emergency dressing and bedroom; office space; supply room; waiting room; toilet; ambulance exit	First-aid and emergency treatment for accidents, should be located in center of work area	30 by 22 ft., 8-ft. ceiling	$2,400	Doctor's office furniture; examination room; emergency bedroom; medical supplies and instruments; heaters
Testing laboratory (concrete, earth, etc.)	Offices for concrete inspectors; curing room; special foundations for compression testing machines	Testing of aggregates and concrete; earth for earth dams, etc.	74 by 27 ft., 8-ft. 6-in. ceiling	$4,300; 17 cts. per cu. ft.	For concrete: 150-ton compression testing machine; screens; 6-cu. ft. concrete mixer; storage bins; tanks; electric drier; work table; curing-room humidity controls For earth testing: ovens; screens; centrifuge; scales and other special equipment; heaters
Warehouse	One-story storage building; 10-ft. loading platform along one side; large sliding doors; floor designed for approximately 275 lb. per sq. ft.	Storage for hardware, supplies, electrical equipment, finish lumber, new tools, and miscellaneous small construction material	250 by 40 ft., 10-ft. ceiling	$10,000; 9 cts. per cu. ft.	Offices for materials clerks and receiving clerks; issuing counter; shelves and bins; cable and rope racks; scales; desks; tables; heaters

Tool house	One-story, simple construction; "in" and "out" doors at issuing counters	Issuing small tools, picks, shovels, boots, raincoats, etc.	48 by 20 ft.	$1,200	Issuing and receiving counters; checking board; tool racks; bins, etc.
Machine, blacksmith, and pipe shop	Double doors and no floor but paved driveway through center; tool room at one end; master mechanic's office; welding bay	Repairs to construction machinery, job fabricating, toolmaking, etc.	100 by 50 ft., with blacksmithy 50 by 50 ft., 12-ft. ceiling	$9,700; 8.6 cts. per cu. ft.; equipment $13,000	Machine shop: 1- to 6-in. pipe-threading machine; ⅜- to 2-in. bolt-threading machine; 9- by 9-in. power hack saw; 6- by 6-in. power hack saw; 24-in. shaper; 24-in. gap lathe; 20-in. lathe; 16-in. lathe; 3- by 6-in. radial drill press; 24-in. vertical sliding head drill; 16-in. pedestal grinder; 8-in. bench-type grinder; 12-in. pedestal grinder; welding outfits; 500-cu. ft. compressor Blacksmith shop: 1 48-in. forge; two 36-in. forges; 3 anvils; power punch; 600-lb. power hammer; quenching tanks
Air-compressor house	Erect building after machinery is installed; heavy concrete foundations	Furnish compressed air to all parts of job for drilling, grouting, cleaning concrete, etc.	40 by 75 ft.	$7,500; equipment, $20,000 to $30,000	Two 2,000-cu. ft. air compressors, one 1,000-cu. ft. compressor; motors and starting equipment; cooling tower (sizes depend on job)
Garage	Special doors; concrete floor; repair pit; overhead monorail, tool room, and office	Repairing and servicing automobiles, trucks, and tractors	52 by 32 ft.	$3,800; 12.5 cts. per cu. ft.	Work benches; battery charger; vulcanizer; hoists; tools; gas tanks; air compressor; greasing tools
Carpenter shop	Standard shop building; special large windows and lighting; large sliding doors; layout and erection platforms; separate office building free from noise	All millwork on wood for special forms, etc.; prefabrication of forms, etc.	Shop 80 by 40 ft.; loading platform, 20 by 40 ft.; layout platform, 50 by 100 ft.	$5,300; equipment, $2,700	36-in. band saw; 24- by 8-in. single-cylinder surfacer; 20-in. planer and jointer; 18-in. swing saw; 14-in. saw table, tilting top
Electricians' shop	Work shop; supplies storage; office; loading platform	Headquarters for electricians and electrical repairs	52 by 24 ft.	$2,500	Motor rewinding equipment; storage bins: soldering and repair tools; wire racks
Riggers' shop	Standard shop with platform for cable reels, etc.	Headquarters for riggers	52 by 24 ft.	$2,500	Cable-splicing rack; cable-reels; block and tackle; bins for cable clips, etc.; office equipment

TABLE 3.—TYPICAL CONSTRUCTION-SHOP AND YARD FACILITIES.—(*Continued*)

Type of building	General features	Purpose	Dimensions of typical buildings	Cost of typical units	Representative list of installed equipment and facilities
Drill-sharpening shop	3 sides and roof; no floor	Sharpening drill steel	34 by 50 ft.	$1,500; 4.6 cts. per cu. ft.	Two steel sharpeners and bit punch; oil furnace and drill rest; fans; quenching tanks; steel storage; drill repair benches
Reinforcing-steel yard	Large storage area and office for foreman	General storage area for reinforcing bars of all sizes and shapes; bending facilities	300 ft. square	....	1½-in. bar size bar tender; 2-in. bar shears; hand bender
Storage yard	Large area of ground with locomotive crane or crawler crane service; railroad or truck unloading, etc.	Storage of large items of construction equipment; permanent materials; machinery; structural members; pipe, etc.	1 or 2 acres with small office for foreman	....	Locomotive crane and track, or crawler crane; blocking; platforms, etc.; pits; trestle; bins
Docks and railroad sidings	Siding track and switches; unloading facilities; cribs; bumpers; capstans; harbor draft for towboats	Receiving terminal for all shipments	Space for 25 to 50 cars; barge tie-up and anchor	....	Warehouse; platform; crane or derrick; cement-handling equipment; hopper for barges under trestle
Power plant	Erect building after machinery; heavy concrete machinery foundation	Generating electric power	40 by 75 ft.	$7,500 and up	Diesel engines and generators; air compressors; oil separators; switchboard; electrical equipment
Powder magazine	Underground dugout or building with heavy walls and light roof	Storage of explosives	....	....	Safety locking devices; fences; separate building for detonators
Oil and gasoline storage	One-story, simple construction; no floor	Shed for storing oil and grease drums; gasoline depot	40 by 20 ft.	$1,200	Racks for oil and grease drums; gasoline tanks; pumps
Portable shanties	Small shanties (on wheels)	Foreman and tools and material protection on job areas	6 by 12 ft. and 10 by 20 ft.	....	Built-in table at one end bench; shelves
Pumphouse	Over well or water; on concrete or pile foundation; corrugated metal building	Job water-supply system, fire and service water	20 by 30 ft.	....	12- or 14-in. pumps; intake; starter; motor; valves; piping

the use of standard steel warehouse buildings deserves consideration because of their high salvage value or usefulness for other purposes.

Reinforcing Yard.—The layout of a reinforcing yard and system of handling steel deserves special consideration. In some cases builders prefer to have all reinforcing steel cut to length and bent by the fabricator, in which case it is necessary to provide a very large storage area for the hundreds of different types or shapes of bars which go into a large structure. This system may have advantages where ample storage space is available and where design details are known sufficiently in advance to permit ordering the reinforcing steel well ahead of actual needs. However, more generally this is not the case, and a very satisfactory system of operation consists of buying various sizes of steel in stock lengths. By properly studying the supply and general requirements the steel may be cut and bent on the job without incurring a great deal of waste. In fact, it is sometimes surprising how small a waste pile finally develops under this system. A yard organized on this basis requires a heavy shear and bending machine which can handle bars at least up to 1¼ in. in diameter. Such equipment is almost essential with any system of handling reinforcing steel because generally changes occur on the job and new design requirements make it necessary to fabricate and bend a certain amount of special steel almost daily.

Power Supply for Service-plant Areas and Shops.—Most of the modern construction projects are operated entirely on electric power, and the location and layout of transmission lines, substations, distribution feeders, and transformers are a major item of planning, as discussed in detail in Chap. XXVI. The most difficult point to determine is the maximum peak requirements of power. An interesting experience occurred at Norris Dam, a project requiring the placing of about 1,000,000 cu. yd. of concrete. The total connected load at Norris Dam was 6,500 kva., which had an annual consumption of 15,738,000 kw.-hr. during 1935. The maximum peak load was 3,100 kva. supplied from a substation with a capacity of 3,500 kva. This margin was so close that when it became necessary to operate the electric heat treatment on the welded penstocks it was necessary to stagger the work so that the heating system could be operated when the rest of the plant was shut down for periodic main-

tenance work. The connected load at the town of Norris was 9,500 kva. This arge load was chiefly due to the electric heating system of the entire community. The annual load factor at Norris Dam was 75.5 per cent against a load factor of 45.3 for the town of Norris.

TABLE 4.—WATER REQUIREMENTS FOR LARGE PROJECT

ORDINARY RAW WATER

	Total Gallons per Hour
1. Foundation cleaning:	
Six ¾-in. water siphons at 1,000 gal. per hr	6,000
2. Core drilling:	
Four 5½-in. calyx drills at 3,500 gal. per hr	14,000
3. Grouting:	
Three 7-in. by 5-in. by 10-in. grout pumps at 4,250 gal. per hr.	12,750
4. Compressor plant:	
Three 2,440 cu. ft. per min. units at 2,320 gal. per hr	6,960
5. Sand plant, 100 tons per hour:	
One 15-ft. and one 13-ft. 3-in. rotary sand washers at 21,000 gal. per hr	42,000
6. Concrete plant three 3-yd. mixers:	
In concrete at 1,670 gal. per hr. per mixer	5,000
Washing waste pit: 1-in. hose at 10,200 gal. per hr	10,200
Washing concrete cars and buckets	100
7. Concrete curing and form washing:	
Eight ¾-in. water lines at 2,500 gal. per hr	20,000
8. All miscellaneous uses	1,000
Total	118,000
Pump installation for preceding:	
Two 8-in. centrifugal pumps in tandem rated at 2,350 gal. per min. at 400 ft. head	141,000
One 4-in. centrifugal pump: 600 gal. per min. at 400 ft. head	36,000
One 4-in. centrifugal pump: 600 gal. per min. at 400 ft. head Used as spare	
Total maximum capacity	177,000
RAW-WATER REQUIREMENTS (SPECIAL)	
1. Sluicing quarry overburden:	
Two 4-in. sluice guns at 52,500 gal. per hr	105,000
The pump installation for this purpose consisted of the following:	
Two 8-in. centrifugal pumps in tandem rated at 1,750 gal. per min. at 600 ft. head	
One 8-in. centrifugal pump as a booster rated at 1,750 gal. per min. at 200 ft. head	105,000
FRESH-WATER REQUIREMENTS (exclusive of camp)	
Fresh water for use in garage, carpenter shop, drinking fountains, sanitary uses, tourist drinking fountains and latrines, offices, etc	3,750

Water Supply.—The problem of meeting the maximum demand for water is equally important. Two supplies are generally required. One, for fresh water to serve the camp for drinking and miscellaneous domestic purposes; this can also be piped to advantage around the work area to provide an ample supply of drinking water to the workmen, which may be further supplemented by water carried on the job. The other, the raw-water supply, is used for mixing concrete, washing aggregates, curing concrete, and cleaning up for new pours, all of which demand a large amount of water. For a job running into about 1,000,000 cu. yd. of concrete, a raw-water storage tank with a capacity of 100,000 gal. is not too small. The variety of water requirements for such a job are indicated in Table 4. Certain features require the use of large quantities of raw water for short periods. Owing to the large volume required, it is generally not feasible to supply it from the plant water system. In cold climates standard precautions against freezing must, of course, be observed. This usually includes heating the mixing water by injecting steam, to provide against the freezing of concrete while it is curing.

Air Supply.—Compressed air is considered an indispensable construction tool and deserves considerable study in planning a service-plant layout. This is discussed in greater detail in Chap. XVI. As a rule, a large compressor station is set up at a strategic point in the job area and from here supply lines radiate in all directions to feed air to the jack-hammers, wagon drills, and other rock-drilling tools. Air is also used extensively in combination with water or sand for cleaning off concrete surfaces prior to placing new concrete on them and for the operation of

Air Compressor Capacities on Large Projects

Dam	Stationary compressors, cubic feet per minute	Portable compressors, cubic feet per minute
Norris	7,140	620
Wheeler	7,516	247
Conowingo	3,400	2,700
Santeetlah Dam	2,500	
Santeetlah Project	10,240*	
Calderwood	6,000	
Waterville	4,000†	

* Stationary compressors for the entire project including tunnels.

† In stationary and portable compressors

cement pumps, gates on gravel bins, various types of air-driven tools and small sump pumps. The equipment in a representative compressor station on large jobs generally consists of units ranging from 1,000 to 3,000 cu. ft. per min. capacity in stationary units. The table on page 35 gives representative capacities which have been installed on large projects.

The most important principle to observe in laying out an air-supply system is the cost of foundations and distribution system and friction losses in pipe lines when using a central compressor plant with stationary compressors, as compared with the maneuverability of smaller units of the portable type. Where a job is spread out over a large area, portable compressors have many advantages and will prove quite satisfactory.

Job Lighting.—There are a variety of ways in which satisfactory job lighting can be provided. At the start of a job it may be necessary to have portable lighting plants on the ground until the regular power supply is available. Considerable opportunity exists for improving the systems of job lighting by erecting high poles with floodlights similar to the ones used for night baseball or football so as to keep as many as possible of the lighting circuits and lamps off the work where they would otherwise be continuslly subject to damage. A very satisfactory system of lighting can be supplied on jobs equipped with cableways by stringing overhead systems from tower to tower with about 1,000-watt lamps spaced at 200-ft. centers.

Employee Transportation.—On certain jobs, such as Hoover and Norris dams, the community was located at some distance from the work, and it was necessary to furnish special transportation facilities. As a rule, such facilities must be available at all times and the proper staggering of heavy-duty transport units with smaller units during off-peak hours offers opportunity for economy.

Heavy-equipment Handling.—At the railroad terminal and at the storage area near the work it is usually necessary to provide a crane, derrick, or other facilities for handling heavy equipment. Selection of the best system usually depends upon a careful study of local conditions. A good storage yard to hold the equipment at the end of the job, combined with proper inspection and records regarding its condition, save time and money in future handling and enhance its salvage value.

CHAPTER V

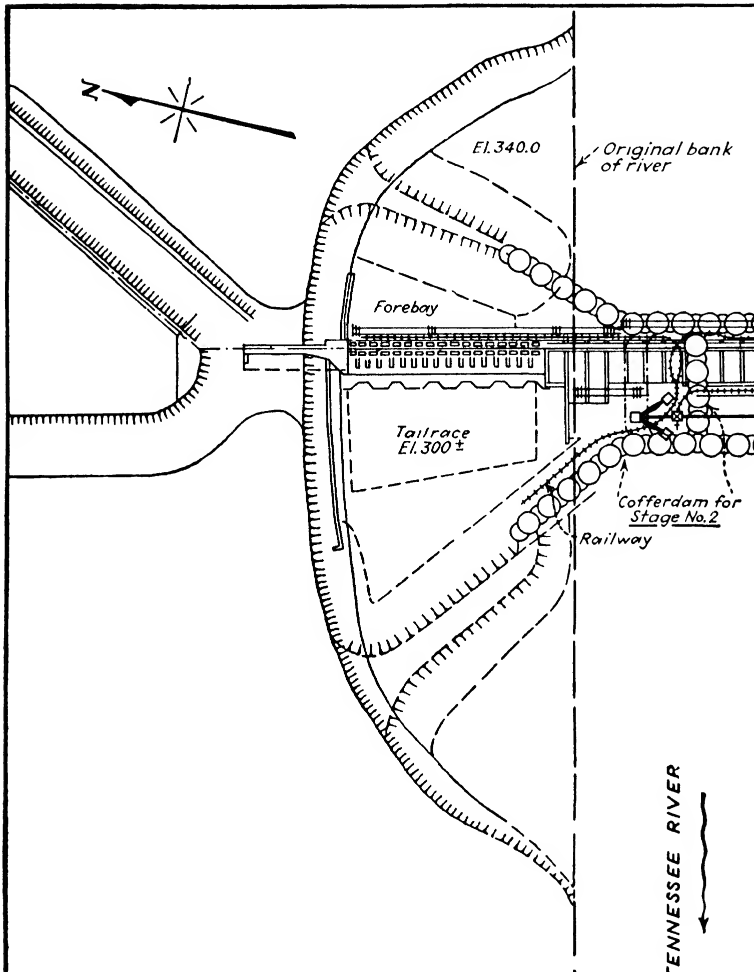
CONSTRUCTION STAGES—GENERAL PLANT LAYOUT

In this chapter we shall get down to the main features of a heavy construction project, dealing in particular with the planning of over-all construction operations and the preparation of all essential schedules. It must first of all be assumed that the construction planner has thoroughly familiarized himself with all the physical and related conditions surrounding the project as listed in Table 1.

The general problems of planning the major construction operations are most readily understood by reviewing a specific case such as the Pickwick Landing Lock and Dam project.

Breaking Project into Stages.—Figure 6 is a general plan of the project. The excavation of more than 1,000,000 cu. yd. of earth and gravel on the south bank of the river was used to build the 1-mi. long earth dam on that side. The area thus excavated provided space for the navigation lock. The spillway, occupying the full width of the river because of its high flood capacity, is a concrete structure throughout, with large steel regulating gates. The intake for the future powerhouse is located entirely within the north bank of the river. Here again more than 1,500,000 cu. yd. of earth had to be excavated to form a tailrace and forebay for the powerhouse and incidentally a diversion channel during construction. This earth was moved to the north bank to form an elevated area above high-water levels for an outdoor switching station.

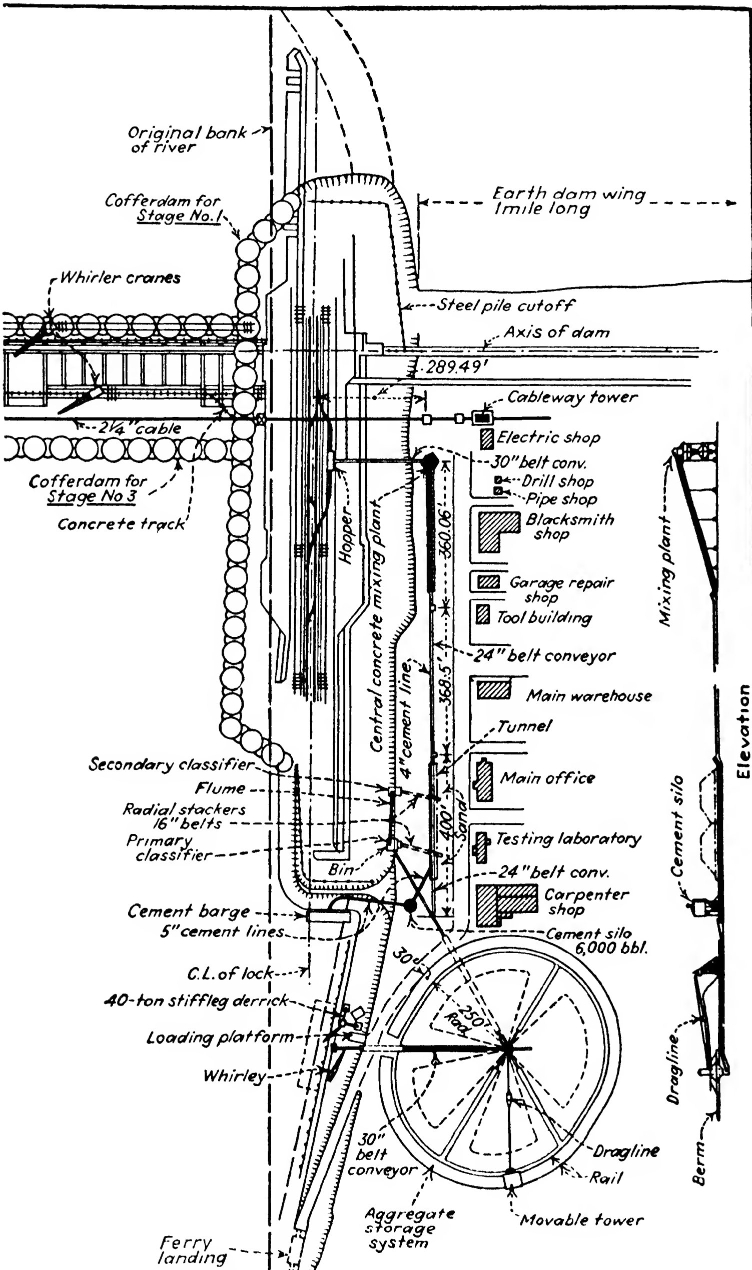
The first idea on an arrangement of cellular cofferdams was to cut the job into four separate stages, but this idea was later abandoned in favor of a better one. It was originally planned first to construct the lock and at the same time carry on operations in the powerhouse area on the other side of the river. Then, the third stage, half of the spillway next to the lock, was to be built while the river passed through the other half represented by stage 4 and through the completed powerhouse intakes.



Max. flood capacities past dam site during construction before overtopping the cofferdams

Stage No.	Cu. ft. sec.	Ave. frequency of floods of this size
1	260,000	Every 4 yr.
2	250,000	Every 3 yr.
3	210,000	Every 1½ yr.

FIG. 6.—Layout of construction stages



and plant for Pickwick Landing Dam.

To complete the work, stage 4, the balance of the spillway, was to be constructed with the river passing through openings in the completed structures.

Final Plan.—In laying out the first scheme of cofferdams it was estimated that 2½ years would be required to build the project. However, after carefully studying river conditions and hydrographs and making various estimates of cost on this and

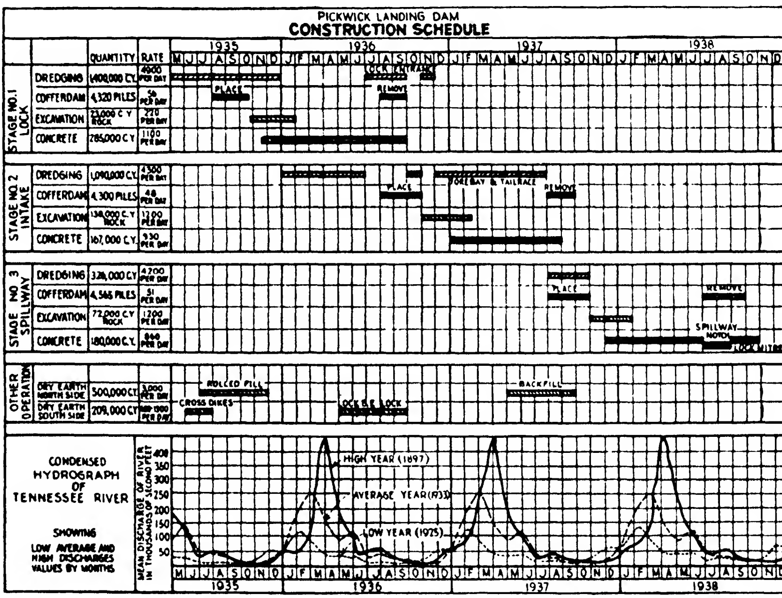


Fig. 7.—Basic construction schedule for Pickwick Landing Dam, and representative hydrographs of Tennessee River, showing flood stages.

alternate schemes, it was decided to adopt the layout shown in Fig. 6. This layout consisted of only three stages, and important economies were introduced by arranging to use the sheet piling three times by first constructing the lock, then dismantling the cofferdam and reerecting it for stage 2, and finally repeating this operation for stage 3. This procedure also resulted in a more efficient use of all construction equipment, although the period of construction was extended to 3 years, with a corresponding increase in overhead and other incidental expenses.

Construction Schedule.—Figure 7 is a sort of "backbone" construction schedule which helps to amplify the reasoning

developed in the layout of the three stages of construction. Representative hydrographs of the Tennessee River are shown at the bottom and indicate the high flood season which occurs in the spring of each year. The construction of the 55-ft.-high cellular cofferdams, being rather hazardous and expensive operations, were scheduled during the most favorable low-water stages. Between these focal operations the concreting program and excavating program were scheduled to tie into the entire operation in the most economical manner. It will be noted that one of the major operations, the removal of approximately 3,000,000 cu. yd. of earth and gravel, was done by dredging and, as indicated in the schedules, this operation was permitted to continue without interruption for about 2 years. Concreting operations, however, were scheduled to be interrupted after the first and second stages. Although it is in general very desirable to avoid such interruptions, the arrangements adopted were found to be more economical. In passing, it should be stated that in preparing such a program the planner must have a general conception of suitable equipment and its daily and monthly performance capacities in order to establish the proper timing for the various operations.

General Plant Layout.—We now come to the selection of a suitable plant layout to meet this general construction program. The first thing to be taken into account was the availability of considerable existing plant and equipment from the near-by Wheeler Dam, then nearing completion. The natural conclusion was that all this equipment could simply be transferred to the Pickwick Landing Dam and there placed into operation without any material modification. Part of the Wheeler plant, see Chap. XXII, consisted of a number of floating mixing plants complete with overhead gravel bins, cement silo and crane for unloading gravel from barges into the bins. A cement barge could be tied at the rear of the mixing barge and from here the cement was pumped directly into the silo. From the mixer, concrete was handled in buckets by a gantry crane which swung around and deposited it in the forms. This plant functioned very satisfactorily at Wheeler Dam and was well suited to the local conditions there, *viz.*, slack water and a navigable depth with practically no variation in water level. By shifting the mixing plant and aggregate barges from place to place along

the mile-long Wheeler Dam, the lateral movement of concrete on land was eliminated.

Most of the Wheeler Dam floating equipment was still in first-class condition, and the first studies were naturally directed toward adapting it to the Pickwick Landing project. A total of 14 rough sketches of preliminary plant layouts were made on outline drawings of the Pickwick Landing project. The preparation of such sketches provides an easy means of getting a lot of ideas—good, bad, and indifferent—down on paper so they can be studied in greater detail, and, by a process of elimination and logical deductions, the most desirable scheme is finally selected. Although in many cases such studies are not made as systematically as was done here, almost every contractor employs this principle when he goes out to look over a job and makes notations of his first impressions on the back of an envelope or other scrap of paper.

The advantages and disadvantages of each scheme were briefly indicated on the various sketches, and by studying these notes in greater detail it was possible to follow through the reasoning on how the final layout was finally arrived at. Starting with study 1, the Wheeler Dam floating equipment was applied directly to the Pickwick Landing project, and certain disadvantages became apparent, particularly those due to the high flood stages which are encountered at this site as compared with practically no flood conditions at the Wheeler site. Double handling of concrete in the lock and other features of inaccessibility soon dictated the desirability of taking the mixing plants off the barges and erecting them at one of several different locations. But there were still objections, particularly from the standpoint of possible shutdowns due to dredging of gravel from the river bottom and delivery to the dam site during the period of high floods.

A further study overcame this objection by setting up a gravel storage system of 50,000 tons capacity on each side of the river which would take care of at least short interruptions in the deliveries of gravel. However, this system meant a considerable increase in plant investment, and further studies led to the decision to provide a single storage of gravel but increased to 250,000 tons. This idea was arrived at through the following reasoning: It was proposed to have the gravel dredged from the river

bottom and delivered to the job by contract. The equipment required for this operation represents a considerable investment and it would have been necessary for the contractor to charge off over a period of 3 years a considerable rental on his plant. Furthermore, if he geared his production to tie in with the consumption of gravel and aggregates in the construction operation, he would be able to operate his plant at full capacity only for short periods and very intermittently.

It was assumed that if the gravel-dredging operations were made entirely independent of construction operations the contractor could operate his equipment at maximum efficiency, permitting him to bid a lower price for the aggregates. This would, of course, result in a high rate of delivery to the job, and it would be necessary to store a large volume. Since a certain amount of storage was indicated as necessary in any case, the additional investment appeared justified in view of the prospects of a lower bid price on the gravel. As it finally worked out, the contractor was able to produce all the necessary materials during the first low-water season and he shut down his plant during the flood season, at which time aggregates were drawn out of storage. In the following spring, the contractor again went to work to rebuild the storage pile to full capacity before the next flood season set in, and at that time enough aggregate was in storage to meet construction requirements for a whole year up to the end of the job. Under this system about 1½ years' rental on the dredging equipment and floating plant was saved, and this saving was reflected in the bid prices, which showed that it was more economical to purchase all the new plant required under this scheme than to employ the existing plant available from Wheeler Dam, even if it had been delivered to Pickwick Landing Dam free of charge.

Individual items from the Wheeler plant, such as mixers, cranes, cement pumps, etc., were, of course, utilized wherever possible before purchasing new equipment but the interesting point of this layout was that where the Wheeler equipment was at one time considered fully adaptable to the Pickwick Landing project, a thorough study of all local conditions resulted in the adoption of an entirely different layout.

It should be noted that each one of the studies on rough sketch paper was transferred to actual scale drawings so that every

feature was brought out in proper relationship and, along with these, numerous cost studies were made of different combinations of cranes, concrete cars, concrete buckets and mixers in different sizes. The necessity of maintaining these units in the most economical and practical relationship toward each other and to the entire plant is obvious, and the principles governing such studies will be discussed in greater detail in succeeding chapters. The adopted layout is shown in true scale in Fig. 6.

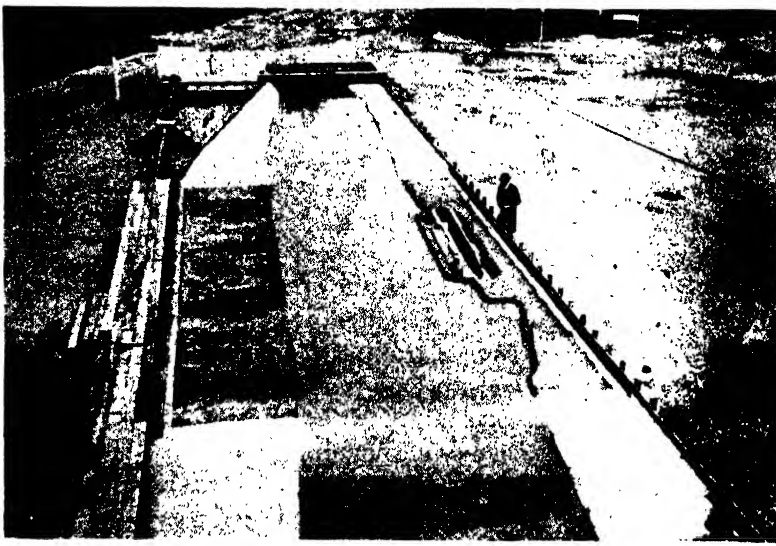


FIG. 8.—Model of Tennessee River at Pickwick Landing Dam site, showing first cofferdam and completed lock, with river at normal stage.

Use of Models for Planning a Job.—One of the major concerns in planning the Pickwick project was the navigability of the river at all times with major constrictions in the channel. To study this, as well as the proper layout of cofferdams and other problems, a model was built to a scale of 1:100 as shown in Fig. 8, and the first point to be disclosed by this model was that the site selected for the harbor for cement and aggregate barges was almost ideal, and that the cross currents which were feared might exist when the river passed through the intake structure would not reach this harbor.

Effect of Seasonal Conditions.—When it comes to the question of protecting against seasonal conditions, each job has its own

particular problem, and it is largely a question of evaluating a shutdown or delayed completion against the cost of protective works and other expenses. A large wooden structure was built over the uncompleted section of a powerhouse in northern Michigan, and within this structure work continued throughout the winter on the erection of turbines, switch structures and all the complicated electric wiring. Local steam-heating coils, and the heating of aggregates and water for concrete, are more common measures of keeping the work going. In contrast to this, on the Madden Dam in Panama where the tropical rainy season tended to hinder placement of concrete, portable panels made up of wood frames sheeted with canvas were assembled over the freshly placed concrete to shed the water and permit concreting to proceed, rain or shine.

Safety Features.—In planning the general job layout one of the most important points to keep in mind at all times is the provision of adequate access facilities for the workmen. Safety is the primary consideration in defining such locations.

CHAPTER VI

PROGRAMMING THE JOB—DETAILED SCHEDULES

Detailed Construction Schedules.—After the general plant layout has been fixed, it is a simple matter to expand into the variety of accessory plant details and to prepare a detailed construction schedule with full knowledge of how each operation will be handled. Such a schedule is largely an expansion of the

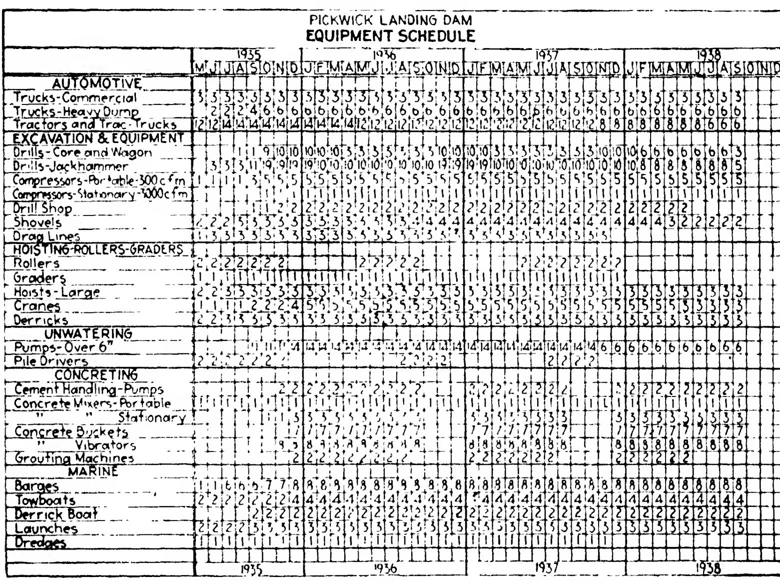


FIG. 9.—Typical equipment schedule for major plant items.

basic operations shown in the "backbone" schedule (Fig. 7). The detailed schedule may contain from 50 to 60 items; in the case of a contract job, the items thus scheduled are usually the bid items.

Equipment Schedule.—With the full construction schedule established, it is now possible to develop a simple but useful equipment schedule as shown in Fig. 9. One of the chief values of this schedule lies in the guide it offers to see that all the

equipment requirements are delivered to the job at the right time. Where equipment is shifted from job to job a reliable schedule of this type is indispensable.

Employment Schedule.—A further important schedule, shown in Fig. 10, is the employment schedule. This not only offers an ideal control of costs by comparing actual labor requirements with those estimated but also helps the key foremen to visualize properly their program as it relates to the selection and training of crews, compensation for turnover, making adjustments to

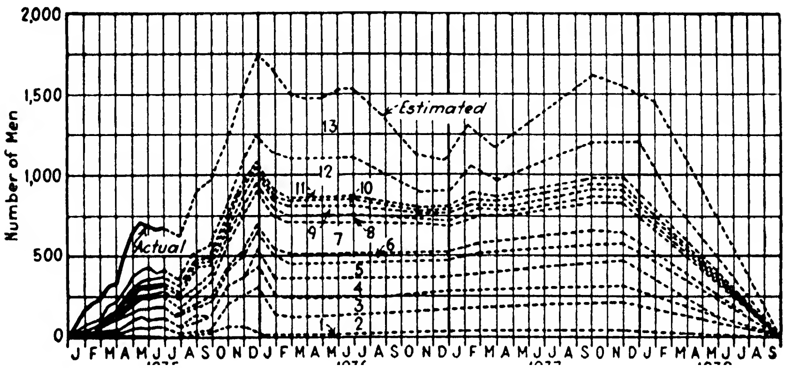


FIG. 10.—Employment schedule showing estimated personnel requirements.

1. Drillers
2. Operators
3. Mechanics
4. Concrete placers
5. Office and engineers
6. Pipe fitters
7. Miscellaneous
8. Electricians
9. Riggers
10. Marine laborers
11. Truck drivers
12. Carpenters
13. Common laborers

fit in with housing facilities and, in general, preventing sharp cutoffs or hurried expansions. This chart may be criticized as appearing unduly uniform, particularly to the old-time superintendents who would go out to the gate on Monday morning, pick up a crew for some special jobs and then drop the men the minute the work was finished. Such a procedure, however, is destructive to the morale of the job and in most cases is quite unnecessary.

It is highly desirable to have a certain amount of work going on which requires considerable unskilled labor, so as to serve as a reservoir for special demands and emergencies which arise from time to time. Some of the common operations usually connected with large projects include the relocation, in the reservoir area, of roads, telephone and telegraph lines, power lines, cemeteries, and occasionally the preservation of items of archaeological

value. In addition, it is usually necessary to raze abandoned structures and clear large wooded areas, including the cutting and salvaging of usable timber and the disposing of waste. All these operations provide ample opportunity for planning employment to compensate for seasonal fluctuations or reductions in the immediate labor requirement here and there.

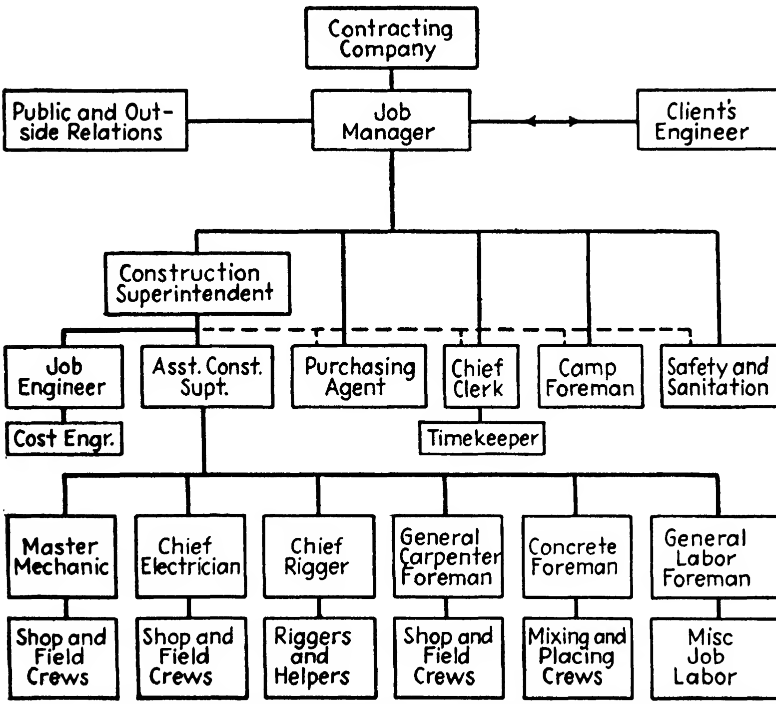


FIG. 11.—Organization chart for large job. On smaller jobs the superintendent usually serves as job manager.

Organization Chart.—Along with the employment schedule the preparation of a construction organization chart is really the first step in planning the entire personnel. Such a chart should be clean cut and fully understandable by all men on the job, and it is a good feature to set it up on a board where all department heads may study it and gain a thorough understanding of their relationship to the entire organization. Such a chart is shown in Fig. 11.

Material Schedule.—Tying in closely with the general construction schedule, the agency furnishing the permanent materials

such as cement, reinforcing steel, gates, generators, turbines, and the thousand and one other items entering into the project must know very early in the job how and when to make deliveries so as to reduce the cost of handling at the job to a minimum. Adequate storage space on the job is, of course, essential, as it is infinitely better to have the permanent equipment on the job well ahead of requirements to insure against the possibility of cutting down operations until certain embedded parts arrive. On the other hand, market conditions and the general problems of designing, inspecting, and manufacturing major items of permanent equipment must be carefully considered in preparing a dependable and practical schedule.

Frequently such equipment may be of assistance during construction. For example, the installation of flood gates and intake gates of large size cannot generally be handled by the available construction equipment, and it is common practice to have the permanent gantry cranes on the job and use them for handling the gates during assembly and subsequent installation in their designated places.

Financial Schedule.—It is important to make a reliable schedule of financial requirements to tie in accurately with the construction, equipment, personnel, and materials schedules. Such a schedule is shown in Fig. 12. It is merely an example and not related to any particular project. At the sides are shown six small charts which indicate estimated current expenditures for each classification throughout the period of construction. Of special importance is the chart showing expenditures for machinery, equipment, camp, and other items which are very large at the *beginning* of the job.

The rest of the small charts are self-explanatory, except possibly the last one, which shows income. A high income is indicated right from the beginning of the job as the result of spreading the cost of camp buildings and utilities, construction equipment, financing, and overhead expenses into pay items which will be started as soon as the job gets under way thereby recovering part of the heavy investment as soon as feasible. In the second year the income is high because the job is scheduled to be in its heaviest activity at that time. However, in the final years the income is quite low, chiefly as a result of spreading most of the major expenses into the first year's operations.

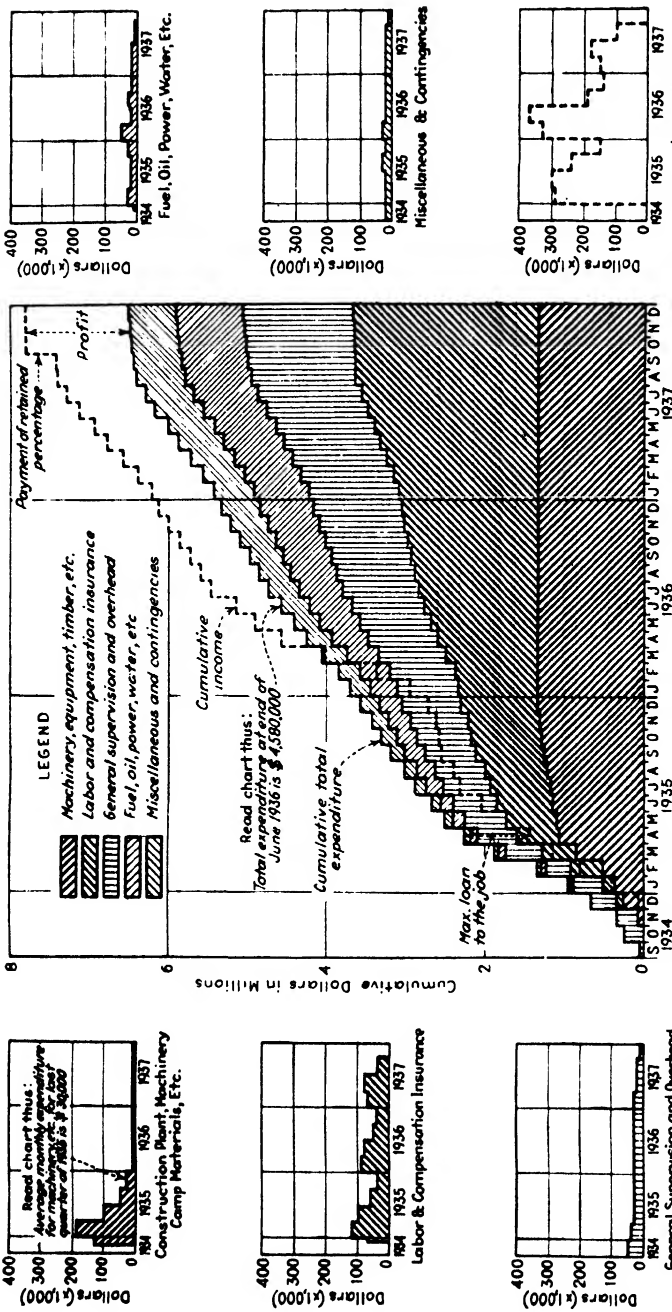


FIG. 12.—Cumulative budget and finance schedule for large construction project, based on average quarterly income and expenditure estimates, plotted on the six small charts.

This, incidentally, is sometimes referred to as "unbalancing the bid"—with all kinds of implications of abuse. Yet it is important to both the owner and the contractor that the latter shall maintain a sound financial position throughout the job, and it is important to distinguish between good financial planning and the abuses of unbalancing bids. Frequently the owner who complains about such abuses may find that they could have been largely overcome if he had set up the bid schedule differently by adding such items as camp buildings, as suggested in Chap. III, concreting plant, preparatory work, etc. The construction industry, of course, is also obligated to eliminate abusive practices.

The main budgetary chart (Fig. 12) is built up by making cumulative additions of each item shown in the small charts. The plant investments are plotted at the bottom of the chart. Expenditures for labor and insurance are added in the same manner and then plotted on this chart by superimposing them to scale on top of the plant investment graph. In this way, the remaining estimates are all superimposed to develop an over-all cumulative expenditure curve. The chart indicates that the total expenditures at the end of the job are estimated at $6,500,000. In the same manner the estimated income has been added cumulatively and plotted on the same chart. The results are especially important from the standpoint of financing because they demonstrate how a job may require as much as 1½ years before total income exceeds total expenditures and shows a profit. The chart further shows how much money must be borrowed to finance the job. This is represented by the maximum amount by which cumulative total expenditures are above cumulative total income.

Control Schedules.—Just as the financial charts indicate ideal control of income and expenditures, so it is necessary to control construction operations in the same manner. For this purpose cumulative construction schedules are prepared as, for example, the one in Fig. 13, which shows excavation progress. As long as the actual performance stays close to the scheduled one or runs above it, the management has an ideal indicator that everything is going well. Similar charts prepared for other consistently recurring operations such as concreting, quarrying, hauling, etc., provide a series of control schedules which are indispensable to the management of the job.

Summary on Schedules.—A big railway system runs smoothly from day to day only because it adheres strictly to a well-defined schedule which is closely observed and constantly held in balance by competent dispatchers. In cases of disrupted service, washed-out tracks, damaged bridges, or derailments, cost is no object in making repairs and restoring all operations to their scheduled channels as rapidly as possible. The same principles apply to a large construction project. The superintendent is essentially a dispatcher who sees to it that his

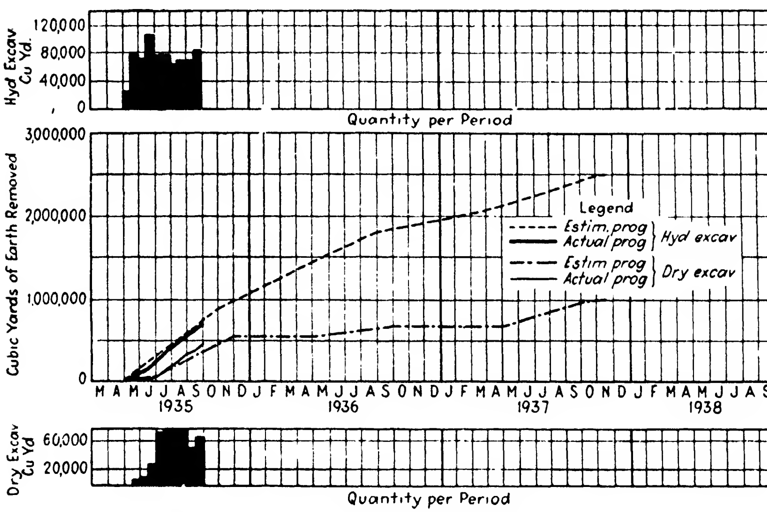


FIG. 13.—Progress chart for excavation program.

schedules are maintained. His job is to keep the whole picture intact rather than to supervise such a detail as the erection of a derrick. With schedules for equipment, personnel, materials, and money properly coordinated there is evidence of sound management and planning, which takes on an immediate importance when it comes to seeking bank loans or other arrangements for financing the job.

Furthermore, throughout the job there is no better way of indicating that it is heading toward success than by keeping all operations along the estimated trend. Naturally, it must be borne in mind that it is impossible to estimate perfect schedules, particularly several years in advance. However, it is important to plan the backbones of the schedules as accurately as possible and to stay with them to the limit. Only in rare cases does it

pay to take advantage of special conditions which may for the moment appear very favorable and profitable if utilized. More frequently such attempts to take advantage of the "breaks" may cause a disruption of the entire schedule and more serious losses at some other stage of the job.

An interesting incident occurred on a recent job when one of the company officials from headquarters' office came around for a periodic inspection and questioned the superintendent regarding the apparently wasteful methods employed in setting reinforcing steel. The superintendent promptly agreed that he was spending about $300 per day more than it should cost and then proceeded to describe the program for the succeeding 3 weeks. Gravel was being shipped in from a distance of 50 miles to meet a definite schedule. Cement, due to arrive 10 days hence, was already being loaded at the mill. The heavy castings which were to be embedded next week were due to arrive within 3 days, and special rigging had been set up to handle them directly from cars into their final position. On top of all this the cofferdams were to be removed and the river diverted through portions of the structures then under construction, and the advent of floods was profoundly regular in its occurrence. All these operations, explained the superintendent, if prevented from continuing along their scheduled way, would so disrupt his work later on that it would cost him $1,000 per day for several weeks to regain his lost ground. So he was ultimately saving considerable money by pushing the setting of reinforcing steel to the limit and almost choking the forms with men who were tying up the bars as fast as they came in.

Tuning Up at the Start.—It is surprising how the time runs by when everybody is busy with plans and preparations. The job can naturally not get under way until the equipment arrives. A serious disruption of the schedule may occur if adequate allowance has not been made for the selection of equipment, market conditions and delays in shipments, together with assembling and erection upon arrival. Most important here is the time required to tune up the plant and eliminate the "bugs" which do not show up until the machinery is put into operation. In a long string of interdependent operations, adjustments must be made back and forth. For instance, in the setting of a crusher to develop the required size of products, adjustments on the screens are needed here and there, a baffle must be added

and guides placed to feed materials properly from one conveyor belt to another, while down under the storage piles the gates must be adjusted to prevent overloading of the reclaiming conveyor belt.

Along with this, the whole crew is "green," and in spite of repeated warnings that this or that might happen unless the operators follow instructions carefully, about the only way some of them learn is by finding out for themselves. It is not surprising that electricians are particularly in demand when a large plant starts up, running back and forth to adjust circuit breakers or to install new fuses. Sometimes the damage is more serious, and it may be necessary to rewind a motor before operations can resume.

It is quite important at all times not to criticize the operators for "honest" mistakes. Many such cases are similar to an unfortunate experience which occurred on a dredging job which was just getting under way. After the first week of operation the new dredging foreman was hailed into the main office of the company and told that his services were no longer required. Wanting to know why, he was informed that he was not producing the results expected of him.

"But," he appealed, "that isn't my fault; I fired two operators already until I got that crew out there to learn that it costs money to take down and clean out a plugged pipeline, and since then everything has been going all right."

"That's just the trouble," he was told. "Those operators were trying to find out how thick a stream they could pump, and now you've got them all scared into pumping water, and they are getting only half the yardage that the dredge is capable of moving."

Summary.—The entire profit on the job is generally made at the start through proper planning and by ironing out on paper the major problems rather than by waiting until it is necessary to make adjustments in the field. Once the general plan, organization, and schedules have been set up, such information can be made to earn big dividends if it is made available to every man on the job. Instead, then, of seeing the loose ends trickle away with the inevitable alibi that, "We couldn't read the superintendent's mind," every one is in a position to help out in the scheme of things by turning "planner."

CHAPTER VII

SELECTION OF EQUIPMENT AND SMALL TOOLS

The fundamental principles of equipment selection are best illustrated by Fig. 14, which shows a comparison of operating costs between two tractors after 12 months of operation on the same job. The performance at the left is for a heavy-duty tractor with ruggedly designed parts and a correspondingly higher first cost than that of the lighter model at the right. Operating costs were proportional to production and are higher for the tractor because it turned out more work. The important point is the low item of maintenance and repairs, consequently less outage time and more working time for the first tractor. To the right is shown what happened to the lighter tractor under rough going. Repair costs were unusually high and the output was lower. The important thing to recognize is that these tractors were links in a chain of major operations, and every time one was shut down the entire operation suffered. It is the over-all cost of delays and general inconvenience and disruption of schedules in the entire chain of related operations which must be considered in the selection of equipment. First cost is generally secondary to reliability. The final result is what counts, as reflected in the unit costs.

Used Equipment.—The same general principles also apply to the purchase of used equipment; first consideration must be given to appraising the useful life remaining in such equipment. Frequently a good investment can be made in the purchase of used equipment for particular operations, but in most cases it is not sufficient to review the history and make a general inspection of the machine. The reliability of the vendor is of equal importance. If the buyer makes proper calculations of operating costs of used versus new and more efficient machinery, he may frequently find that jumping at bargains may be a shortsighted policy.

Standard Equipment.—The smaller jobs must depend, in almost every case, on the application of standard units, and

where such units are readily adaptable to a variety of applications, such as a shovel convertible into a dragline or crane, the investment for plant can be held to a nominal figure. However, the very nature of a small job frequently demands more ingenuity in laying out plant requirements than is sometimes displayed on big jobs where there is a tendency automatically to take a large investment in plant for granted.

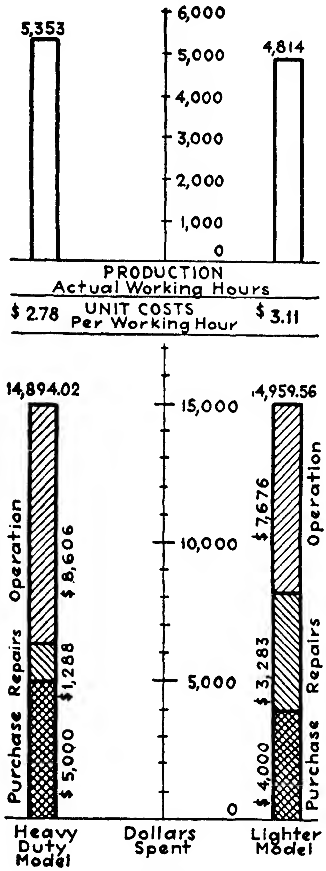


FIG. 14.—Operating costs over a period of 12 months shown graphically for two types of tractors.

Although the equipment manufacturer is constantly seeking to provide the contractor with more universally adaptable machinery, he is also confronted with the necessity of limiting himself to a certain policy of standardization. Among the valuable features which have been developed by manufacturers in the last few years as an aid to increased earning power for the contractor, are the following: Change-over from gasoline engines to the more economically operated Diesel engines; introduction of special alloys and metals, such as aluminum booms on drag-lines for increasing the reach, speed, and capacity of the machine; aluminum buckets; change-over from slow, manually operated levers to easily manipulated hydraulic, air, or electric controls on excavating and hoisting machinery. Along with all these improvements has come the all-important development in greater safety features.

Special Equipment.—The very fact that the manufacturer is in general building a standardized line does not close the door, of course, to his cooperating in the development of special

features. However, the buyer presumably is the only one who fully knows the need for such special requirements which may be peculiar to his job, and he can frequently increase his earnings considerably by working out special modifications and have them either installed by the manufacturer or designed and made right on the job. This function of plant designing is only one step removed from designing a special plant for a large project. However, emphasis is again directed to the point that even in

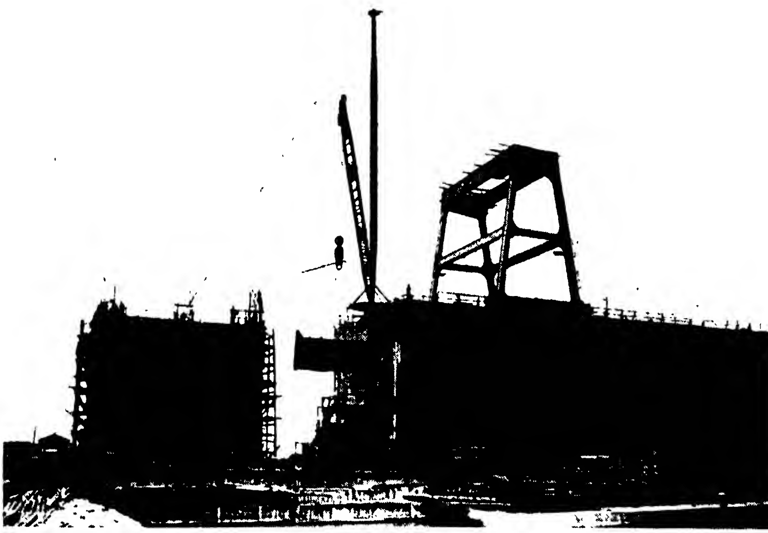


FIG. 15.—Special setting of guy derrick used to erect gantry crane and handle heavy castings at Wheeler Dam.

large special plant layouts, the most successful design is the one which utilizes and adapts, as far as possible, standardized equipment.

In all processes of plant selection, full consideration should be given to the availability of spare parts from near-by sales and service depots, in addition to having a generous supply of such parts on the job at all times. This feature also brings up the point of standardization of equipment. The economies therefrom are quite obvious when considering investment in spare parts and the all-important factor of simplifying the job for maintenance and repair crews and interchange of operators.

Small Tools.—Along with the basic setup of plant and equipment to take care of the fundamental routine operations, there are thousands of special operations which must be adequately provided for. The development of small tools for large jobs has in many respects been remarkable and not fully appreciated by the foremen, who should be most familiar with them. Numerous types of air-driven equipment—such as hoists, sump-pumps, and wrenches—acetylene torches, chain hoists, portable electric saws, portable electric welders, small utility cranes, and a variety of smaller tools are indispensable on a large construction job. A great deal of money is lost by permitting heavy-duty equipment to do jobs which some of these smaller units can do as well, and frequently the smaller tools are in a position to earn more per dollar invested than can be gained from the heavy-duty equipment used promiscuously on various odd jobs.

Special Erection Problems.—Another special type of problem on every large job is the erection of heavy equipment, such as spillway gates, lock gates, turbines and generators, cranes, gantries, and bridge girders. First of all, it is important that the superintendent make adequate advance plans for proper shop assemblies into such size and weights as can be readily handled on the job, and along with this, the arrival on the job must be carefully scheduled. For erection, special setups of derricks, cableways, gin poles, or other erecting and hoisting machinery are required. Such a setup, illustrated in Fig. 15, shows a carefully spotted guy derrick which is being used to assemble a large gantry crane and at the moment is delivering some heavy castings from the barge in the foreground to the powerhouse area on the other side of the intake structure. Incidentally, this gantry crane is being erected almost a year before the powerhouse is to be placed in actual service. In the meantime, the crane will be used in assembling the intake gates, setting them in their designated places and manipulating them during the remaining construction period for passing the river temporarily through this structure while the final portion of the main dam is being completed.

CHAPTER VIII

MEASURING EQUIPMENT PERFORMANCE—ANALYZING REPORTS

Everyone experienced in modern manufacturing methods takes it for granted, upon entering a large machine shop, that he will find careful records being maintained on each individual machine with respect to identification, number of hours working, regular attention to maintenance and oiling, detailed records of any repairs, including nature of repairs and their costs, speeds of operation, productivity of the machines, etc. All these records are carefully analyzed to discover ways and means for improving the reliability and increasing the productivity of the machines.

These are exactly the same operations and observations which should be maintained on every construction job. It is surprising to find on many jobs that superintendents take as a matter of course the keeping of a detailed record of $4 or $5 daily expenditures on a man's time, yet have practically no operating records whatever on a machine whose time is worth $50 or $100 per day. Too frequently the attitude is taken that as long as the shovel is bailing out dirt everything is o.k., whereas a careful study of operating performance may disclose that the shovel is performing at a daily use efficiency of only 60 to 70 per cent. There is no substitute for accurately maintained records of performance, and they will pay for themselves many times over if they are carefully studied and judiciously used.

Property Card.—First of all, there should be a convenient record card showing in detail the general description of the machine including: manufacturer's specifications, and serial number, date of purchase, price, weight, all principal dimensions, names of accessory equipment, etc. Not only is such a record of value to account for the property, but it is very handy reference for the construction planner in studying further uses of the equipment.

Records Which Help to Keep Equipment Working.—A successful construction superintendent was discussing some of his early experiences as follows:

When I was learning this business as an excavation foreman on some of the jobs down South we had an old superintendent who never felt happy unless he had 8 or 10 derricks set up and a bunch of extra equipment on the side line just so he would be able to do what he wanted to do when he wanted to do it. It never looked right to me. It so happened that we were working near a small town and every day an Italian came by the job with a horse-drawn peanut roaster. I used to kid old Tony, and one day I said to him, "Tony, don't you ever get tired of running this old hack around the town and listening to that squeaking whistle?" Tony answered right back and said, "Ah, no, boss! No toota da whistle, no make-a da mon."

You know I have often thought about that. There was Tony with his money invested in an old plug and a peanut roaster and as long as he was keeping his outfit working it was paying him dividends. This construction business is about the same when you consider all of your equipment an investment which will earn money for you only as long as you keep it going. I have always worked on the principle that it is better to wear out the equipment rather than to let it rust out.

This principle is certainly important and a great deal of effort is justified in developing a system of control which gives the superintendent full information of what is happening on his job in the way of keeping the equipment working as nearly to its full capacity as possible. One of the simplest forms is shown in Fig. 16, which shows an Equipment Use Report. This report is placed on the superintendent's desk every morning, and he sees at once what equipment is working, what is under repair, and what is idle. Furthermore, if he knows what his equipment is doing, he knows what his job is doing.

However, it is not enough to know that the equipment is busy. Of even greater importance is to know *how* busy it is. This cannot be established effectively by the simple expedient of having the foreman keep an eye on it. In the first place, such a procedure is too expensive and, in the second place, it does not tell the story. Real control over equipment performance is obtained by recording its operations continuously, as for example, on graphical meters. A careful study of the recorded charts will reveal many unsuspected elements and opportunities for

lower unit costs. The investment in metering equipment is generally a fraction of the saving which can be developed, not only in lowering the costs on the machine which is directly under observation but also, where the machine is a controlling link, in improving production all along the system. Leaks of dollars on bad equipment are quickly detected, and frequently redesigns can be made right on the job to stop such leaks.

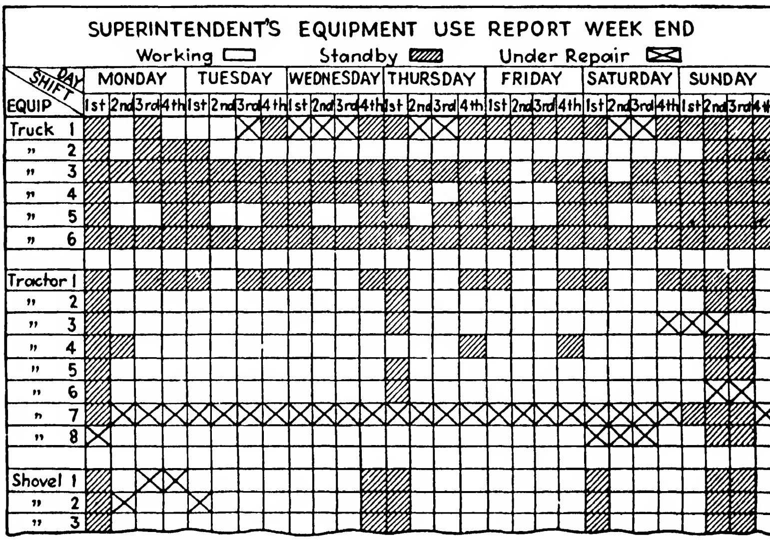


FIG. 16.—Weekly equipment use report tells superintendent what machines are working, idle, or under repair.

Graphical Meters.—A graphical wattmeter was installed on the feeder circuit of a large motor on a hammer mill in a sand plant. The charts were used to establish what type of hammer and kind of metal would be most lasting with the rock quarried on this job, and many thousands of dollars were saved as a result of these observations. Furthermore, the charts provided a direct indication to the operator for controlling the load of incoming stone at maximum efficiency without overloading the mill. The net operating time of the machine was disclosed, and any unnecessary delays or interruptions caused at other points were clearly indicated and promptly corrected. With the charts once calibrated, they gave a daily record of tons of sand produced.

The Service-Recorder is another type of recorder which is very simple, compact and portable. It is driven by clock mechanism

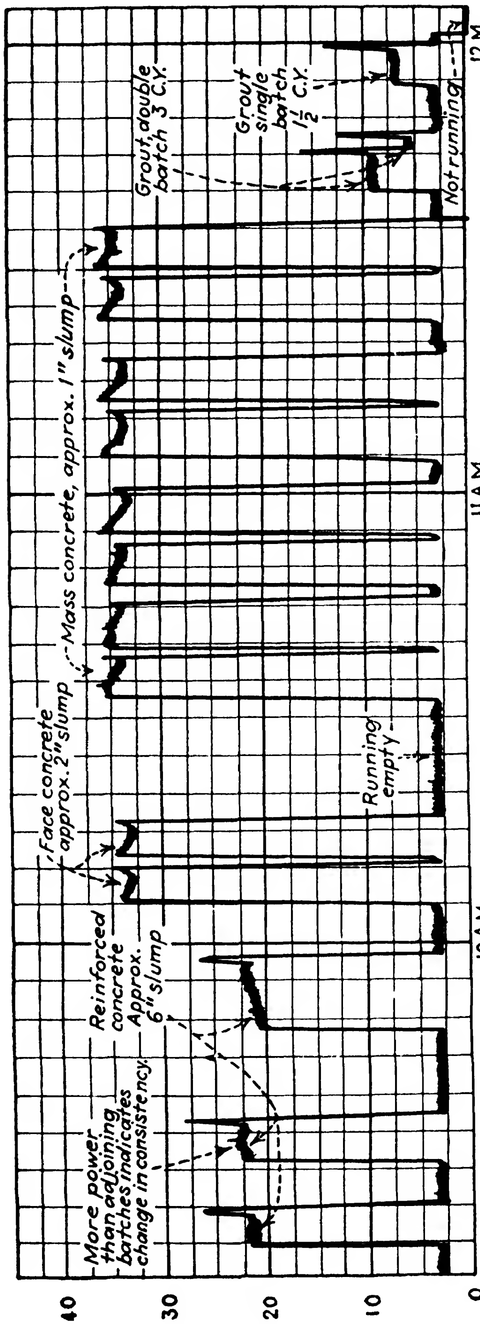


FIG. 17.—Chart from a recording wattmeter in a concrete-mixing plant.

and can readily be installed on a truck or on any device which vibrates sufficiently when in operation to actuate a small stylus attached to a sensitive pendulum. A large amount of information is obtainable from its charts. This includes a record of frequency of use, time of operation, average speed, frequency and extent of delays, and similar items. It is obvious that when such charts are discussed with the operator in charge of the equipment a very effective basis is provided for improving results.

Another type of record from a recording wattmeter is shown in Fig. 17. The meter was connected to the motor of a concrete mixer in a mixing plant. The meters from all three mixers were located at the inspector's desk, and he knew at all times what was going through the mixers merely from observing the charts. He could see how long the batch had been in the mixer, when the mixes changed from mass concrete to thin concrete or grout, or when the consistency of the mix changed due to excessive moisture in the sand. With such indications he could promptly make the necessary corrections for maintaining the desired water-cement ratio in the concrete. At the same time this record provided a convenient check on the number of batches per day. Knowing the cement requirements for the different types of batches, the operator could check back on the total cement consumption.

A further example of a recording from a graphical meter is shown in Fig. 18. In the operation of a large cableway the question arose as to how different operators handled the cableway controls and what their effect was on the circuit breakers and other electrical equipment. By connecting a recording wattmeter to the main hoist motors these charts were obtained. Much to the surprise of every one they indicated a tremendous amount of fluctuating power passing through the electrical system. The severe service placed upon the electrical contactors was clearly indicated by the varied methods employed by different operators in handling the controls. The operating cycle was in every case almost identical. With such a record it is considerably easier to instruct the operator in changing his technique, as he is generally quite proud of his ability and feels that the way he is doing the job is the only correct way. These charts also provide a check on the operator's reports of idle time,

delay, and working conditions, together with a count of the number of loads handled.

Checking the Entire Job.—As previously stated, the proper application of recording graphical meters will occasionally disclose surprising information, as occurred recently on a large job where the superintendent decided to get a more accurate record of how efficiently the work was carried through at changes in shifts. He connected the wattmeters to the main substation

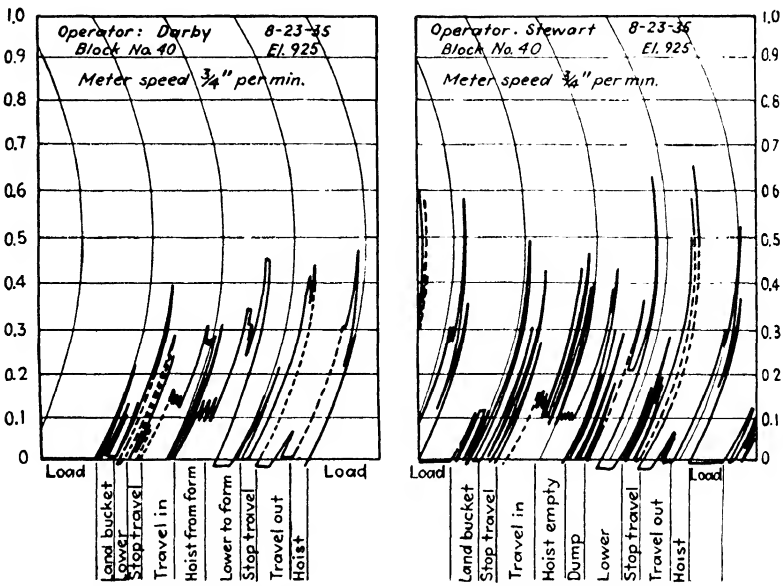


FIG. 18.—Graphic record charts of current in cableway hoist motor, showing good and bad operation over a complete cycle of handling concrete bucket to and from form.

circuit. The record from the power feeder running to the air compressors was a startling bit of news because it showed that at shift changes at 6 and 12 o'clock sometimes as much as ½ hr. was lost from the time drills and other air consuming equipment were shut down until they were started up again by the next crew. Naturally this disclosed to him immediately where he had to "put on the heat," and it wasn't long before he got much better recordings and practically no losses in time as the crews went off and on.

Analyzing Daily Operators' Reports.—In addition to graphical records there are, of course, the operators' daily performance

reports which, when properly analyzed and recorded, provide a considerable amount of valuable information. Figure 19 shows a chart made up from daily reports on an elevating grader and trucks; this at once gave the superintendent a clear picture of day-to-day performance. Of particular interest is the time required to get the operators broken in and build up the system to full capacity, which took about 20 days.

The upper chart shown in Fig. 19 was made up for the superintendent's own information. A similar record from the same operating reports was made up for the benefit of the foreman and operators on the job; this is also shown in Fig. 19, which is especially designed so it is readily understood by the operators. The chart was mounted on a board 24 by 36 in. and posted at the site of the work. Improvements in performance are clearly indicated, for example, by comparing the loads handled during July with those handled in succeeding months. It was surprising how these charts stimulated competition and rivalry between shifts, together with the usual number of alibis, many of them quite real, of course, from the crew that made the least number of loads. Naturally many of these complaints contained valuable suggestions to the superintendent which he could use for improving operations. The net result was a keen appreciation among the operators that the management was giving full recognition to what they were producing.

Figure 20 is an interesting chart because it indicates the possibilities of showing graphically a large amount of data which, in this case, was prepared from about 20 pages of typewritten material. The chart shows the result of tests made on wagon drills in a quarry to determine the effectiveness of three different makes. All the production information, in number of lineal feet drilled and different depths of holes, is shown in direct relationship to actual performance and the various kinds of losses in time which were incurred during these tests. The influence of various types of losses upon total drill performance and comparison between different makes and average results are all clearly shown pictorially on this one chart.

Figure 21 is another type of chart which is of considerable importance to superintendents and foremen assigned to operations which are recurrent and routine, as in this case, where three 5-cu. yd. trucks were transporting sand a distance of

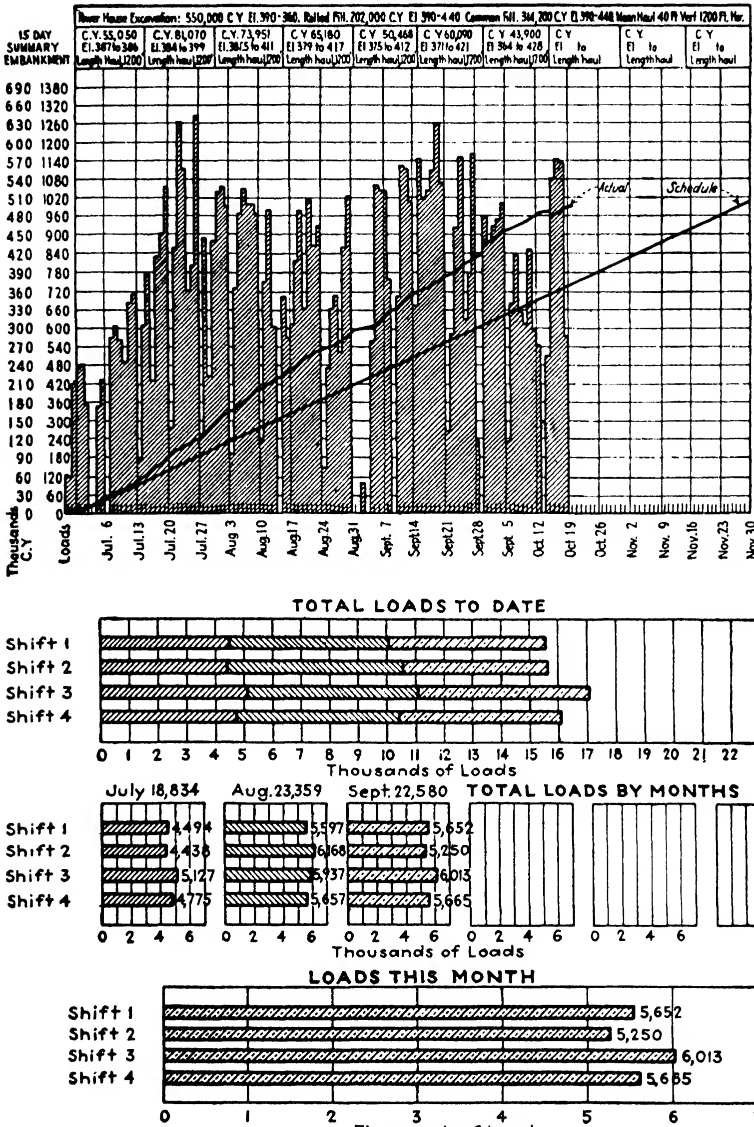
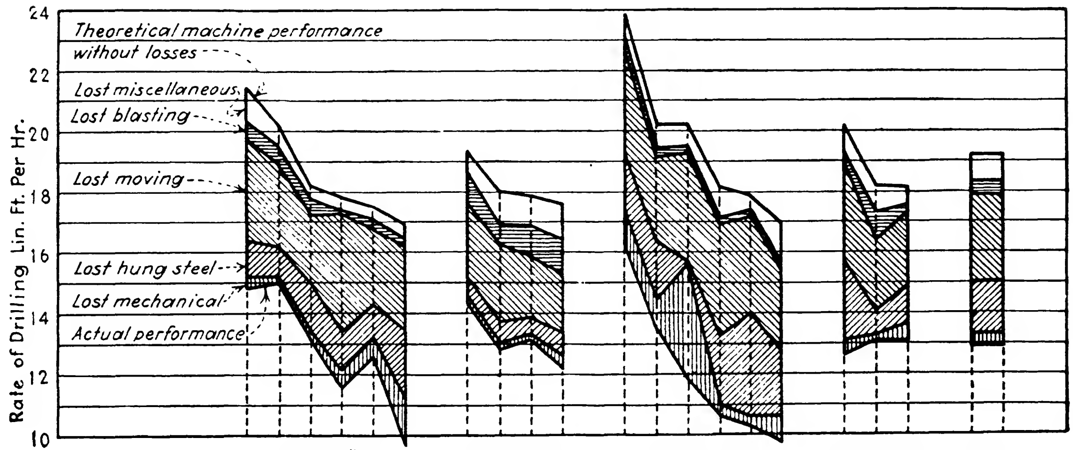


FIG. 19.—Progress and performance chart of elevating grader and truck-wagons on an excavation job gives the superintendent and crews a picture of the daily performance by shifts.

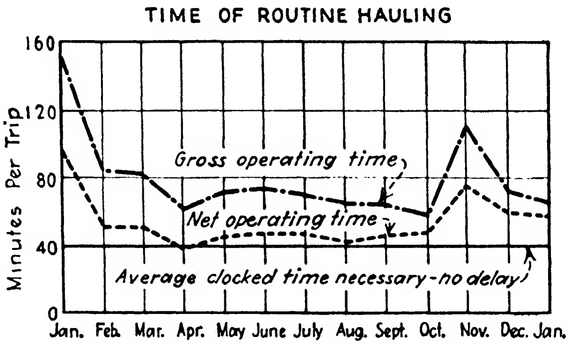


DRILL NUMBER	MAKE "A"						MAKE "B"				MAKE "C"						BY MAKES			ALL	
	4	2	3	13	1	14	8	7	6	5	9	10	16	12	11	15	A	B	C		
Lin. Ft.-12' Blast Holes	2948	2920	1717		1418		3350	1670	3563	2293	4829	1295					6124	10876	9003	26003	Foundation Area
" " -20' Grout "						214		131	265	159		83	278	100	151	140	752	555	214	1521	" "
" " - 30' Grout "					55	304	964	672	577	806	491	785	778	271	45	103	2473	3019	359	5851	" "
" " - 30' Blast "	1787	1974	1929	1858						996	2029	2285		1880			6194	996	7548	14738	Main Quarry
" " - 40' Grout "					2699	1974	52	63	100	38	387	662	4311	2032	2240	2352	11984	253	4673	16910	Foundation Area
" " - Total Holes	4735	4894	3646	1858	4172	2492	4366	2536	4505	4292	7736	5110	5367	4283	2436	2595	21527	15699	21797	65023	

Test - April 25 - May 25, 1934

FIG. 20.—Chart of wagondrill performance showing method for conveniently recording large amount of data.

4 miles and operating on four $5\frac{1}{2}$-hr. shifts, or a total of 22 hr. per day. This operation was going along to the apparent satisfaction of every one concerned until it was decided to make a time study and actually see what was going on. The gross operating time was first plotted on the chart. This represents



DAILY HAULING RATE (7 Trips per Truck Shift)

No. Cu.Yds.	No. Loads Required	No. Truck Shifts	NO TRUCKS PER SHIFT 1	2	3	4
175	35	5	3	2	-	-
210	42	6	3	3	-	-
245	49	7	3	3	1	-
260	56	8	3	3	2	-
315	63	9	3	3	3	-
350	70	10	3	3	3	1
385	77	11	3	3	3	2
420	84	12	3	3	3	3

FIG. 21.—Study of truck operating time in hauling sand. Also table of instructions for hauling various loads per shift.

the time for which the drivers actually received pay. Along with this the net operating time also was plotted, which showed the reported truck time when the truck was actually hauling the sand.

The average gross operating time was 76 min.; the average clocked time necessary to make the round trip, with no delays, was 40 min., so that there was an apparent delay time of 36 min., almost half of the gross time. As a result of this study, a table

was prepared (shown in the chart as "daily hauling rate") which gave a schedule for the same operation based on 47 min. for an average round trip. Depending upon the demands for sand for a given day, the foreman immediately knew how many trucks he must send out and how many shifts he must operate them. Although it may at times be difficult to follow exactly such a schedule, it can at least be approximated and result in the elimination of costly delays.

Major Replacement Record.—Another type of chart can be very helpful where large supplies of replacement parts must be kept on hand at all times, as, for example, on a dredge operating in an abrasive material with the resulting high wear of hub-shells, propellers, and many other parts. A suitable chart gives a full history of performance, indicating the life in each part as well as number of parts on order and in stock and parts repaired and returned to service. Generally such parts are rather complicated castings which may require from 1 to 2 months between the date of order and arrival on the job. This sort of record keeps the superintendent from getting into the hole.

Economic Life of Equipment.—The best way to know that equipment is operating on a profitable basis is by keeping accurate records of the *rate* of repairs and depreciation. For cost-keeping purposes it is general practice to estimate in advance an hourly rate for each piece of equipment, based on past experience. However, this is at best a good guess; the rate of repairs and depreciation and its relationship to output is actually a variable during the life of the equipment and therefore requires close attention. Figure 22 shows a graphical method employed by P. H. Kline for observing the change in hourly rate and the economic life of a piece of equipment. In the example the equipment cost was $10,000 new. Repairs were low at the start but in time the repair curve went up at a faster rate. At 10,000 to 12,000 hr. the hourly rate became stabilized at a minimum of $2.40 per hr., somewhat below the estimated $2.50 rate. Later repair expense and outage time are indicated to be at a higher rate and the equipment is now entering its uneconomical life zone. The $2.40 average rate can thereafter only be secured by a new unit, or might even be bettered by a new improved unit. The time for considering replacement or trade-in has arrived, in so far as operating conditions govern. (There may be other

factors such as lack of new capital or interest charges which might justify continued operation for a limited period of time.) If a contractor keeps this kind of a record for each piece of major equipment he has an exact record of the condition and status of his plant.

Combination Progress and Cost Report.—One of the most important charts is shown in Fig. 23. This type of chart may

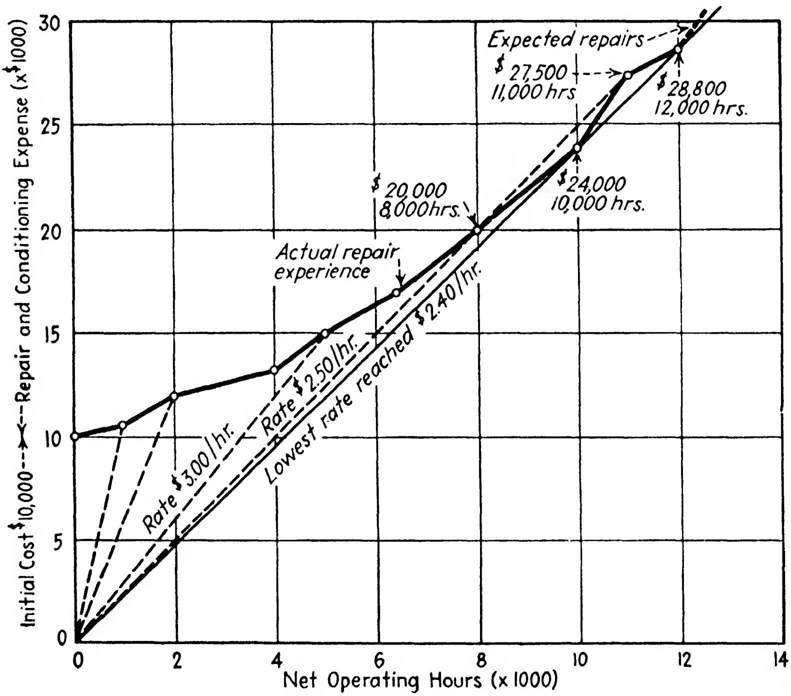


FIG. 22.—Chart showing method of determining economic life and rental rate on construction machinery.

be prepared for any operation running continuously through the job—for instance, the performance of a mixer plant which is here shown. The upper part of the chart shows cumulative production as compared with scheduled production and also the monthly output of the plant. A series of similar charts on all major operations tells the all-important story in dollars. Of particular interest is the high cost of operation at the start in getting the plant underway and systematizing operations. The high unit costs at the start are of course also accounted for by the

low production and this brings out the important fact that in starting up a new plant every preparation should be made in order to permit production to get up to full capacity as soon as possible.

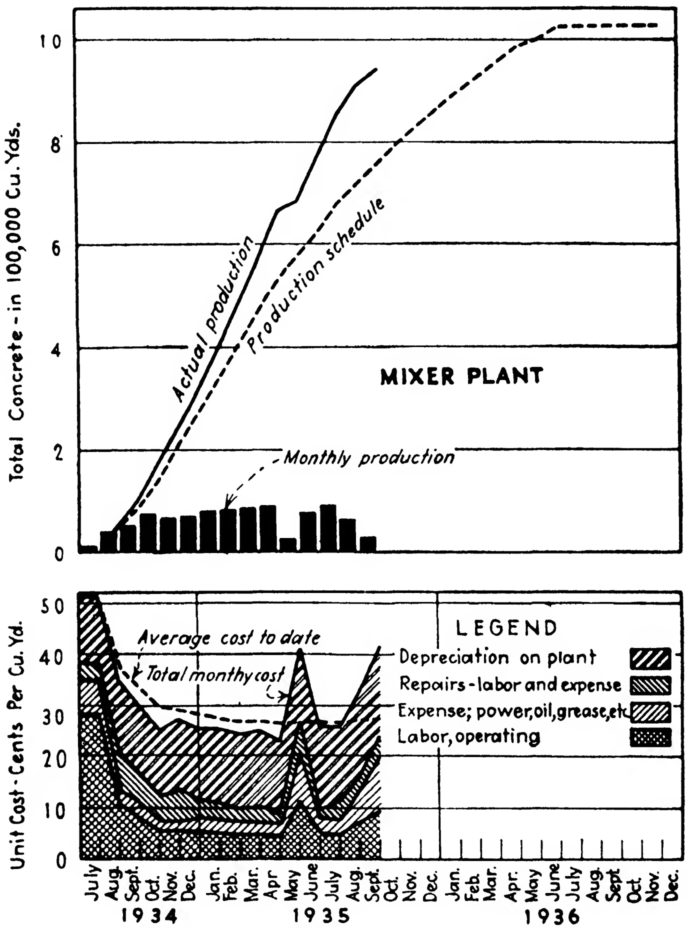


FIG. 23.—Combination progress chart and cost report for mixer plant.

Of further interest is the experience of June, 1935 when a breakdown outside of the plant caused the whole job to operate at only part capacity and the unit cost immediately jumped up. Beginning in August, 1935, the job began to wind up and here, again, daily production went down with a corresponding increase in unit cost because the plant was no longer operating at its full

capacity and maximum efficiency. When these various points are properly appreciated and anticipated the opportunities for saving money are apparent.

Incidentally such cost charts reveal for future reference the important difference between average costs over the full period of the job and the best costs which are obtained when everything is running at full capacity.

A study of such performance records, and interpretation for the benefit of the superintendent and foremen on the job, can be handled to best advantage by specially trained technical men who have a thorough understanding of construction costs, machine performance ability, and the human element of job operations. Obviously, the superintendent has not the time to make such studies, and the foreman in general does not have the training, nor should he be required to spend his time in making such studies. Where facilities are provided for assembling such information for the purpose of finding out how to improve operations and reduce costs rather than for the purpose of finding out who is wrong, such facilities will pay for themselves many times over.

CHAPTER IX

COFFERDAM DESIGN AND CONSTRUCTION

One of the biggest opportunities for economy in the construction of a dam rests in developing the best possible scheme for handling the river. The real test of superior judgment in this respect depends upon the most logical consideration given to the following five questions:

1. River Regimen.—What are the flood characteristics of the river? This requires a careful analysis of hydrological data extending as far back as possible. Annual hydrographs bring out the occurrence of seasonal flood and low-water conditions, as well as the history of unexpected off-season floods. Where suitable discharge records have not been kept, it is frequently necessary to interpolate by an analysis of rainfall data and their characteristics of runoff, or by a study of similar adjacent drainage areas.

2. Flood Hazards.—What are the flood hazards and what risk should be assumed by the constructor? It is one thing to *gamble* on the probability that no flood will occur during the construction period; it is quite another thing to apply sound judgment to the estimating of flood damages and cost of delay to work, and to estimating the point where additional flood protection would cost more than the damage which might occur. In developing this judgment it is necessary to study flood frequencies on charts such as the one shown in Fig. 24, which indicates the frequencies for each month; such a chart is valuable in relating cofferdam heights and construction stages for maximum economy to the general pattern of flood frequencies and probabilities throughout the year.

3. River-handling Methods.—What is the most economical type of channel for handling the river during construction and for making diversion and final closures? A careful study must be made of the following: seasonal flow conditions; discharge capacities of the constricted river channel when partly coffer-

dammed off; hazards and difficulties of diverting the river from its natural bed into a new diversion channel or into diversion tubes; and, an economical balance between hydraulic capacity of such diversion passageways and their cost of construction, including the necessary appurtenant gates or other elements for making the final closure when the dam is completed. The study of these problems on hydraulic models, as illustrated in

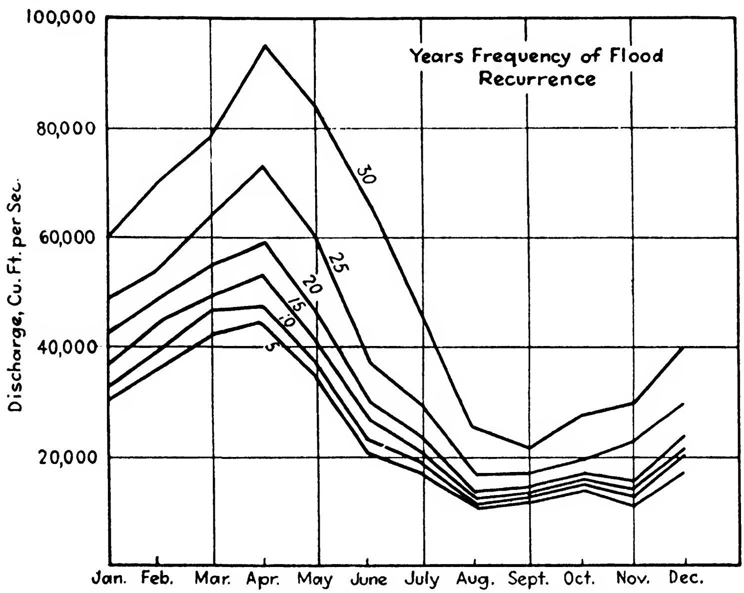


FIG. 24.—Flood frequencies plotted for each month define flood probabilities and indicate necessary cofferdam heights.

Fig. 8, is justified in practically every case and generally will point out important economies in design or construction which will save the cost of such a model many times over. In any case, the model will confirm the soundness of the proposed river-handling methods and in this respect is equivalent to an insurance policy against otherwise unforeseen construction risks and hazards.

4. Cofferdam Type and Height.—What are the most economical type and height of cofferdam? This involves a thorough analysis of available materials, foundation conditions, tendency to scour either around or under cofferdams, methods of waterproofing, and probable leakage and pumping requirements within the

cofferdam. In the majority of cases it is not economical to build a cofferdam to such height that protection is provided against the most severe floods. At Bonneville Dam, on the Columbia River, it was found necessary to limit the height of cofferdam and allow the flood season to cause suspension of the work for more than a month during each year, and the water was permitted to rise 10 to 15 ft. over the top of the cofferdam.

On most jobs it is necessary to provide only for the probability of flooding if seasonal conditions should turn out to be unfavorable. However, here again the proper design of the cofferdam to withstand overtopping is an important factor. In such cases it is common practice to provide gates or other means for filling the cofferdam area at a moderate rate, before the crest of the flood arrives, to prevent damage which might otherwise occur from water falling into the area from all sides. An important relationship to keep in mind in the design of cofferdams is that greater capacities in the diversion structures, mentioned under paragraph 3, will often mean lower cofferdam heights, and this calls for a careful study of the proper economic balance.

5. Construction Sequence.—What is the most economical sequence in building the various stages of the structure? Except in cases where it is possible to divert the river into a tunnel or other channel where it offers no further interference with construction operations, it is necessary to handle the river one or more times and provide suitable space in the partly completed structure for diversion passageways. This usually results in the dam being split up into stages of varying magnitudes. Here, again, money can be made or lost, depending upon the sequence which is laid out for building the various stages, because this directly affects the entire construction-plant layout. It is important that diversion procedure and cofferdam heights be in proper balance with the ability and limitations of the construction plant. Major economies can be developed if the stages are laid out and properly coordinated with the range of operation of the plant, so that in most cases there is always a place to deposit concrete and thus allow the plant to operate continually at a high rate of production. It is not enough to set up a fine plant with a capacity of, say, 3,000 cu. yd. of concrete per day, although this may be the correct capacity, only to find that the diversion program has split up the job to such an extent that concrete

can be deposited at an average rate of only 2,000 cu. yd. per day because there are not enough other places available for placement. For a given speed of construction the real economies come from operating a plant at its capacity output as much as possible.

The foregoing may be translated into the following mathematical expression: plant cost, plus operating cost, plus river-handling cost, plus miscellaneous costs should produce the minimum cost of the project. This equation must be correctly solved before the job starts, in order to develop the biggest profits or economies. One of the first decisions to be made on a new job is how much to spend for plant. It is easy enough to see from the equation that a higher plant cost is sometimes justified where this will permit a corresponding reduction in operating cost and river-handling cost, and a decrease in attendant uncertainties. It takes sound judgment and courage to spend enough for plant to develop the lowest summation of these costs.

Earth-fill Cofferdams.—The simplest type of cofferdam is an earth-fill levee which can be used to advantage where the material has the characteristics of stability, compactness, and imperviousness. Such cofferdams, however, can be employed only for limited periods of time and where overtopping or scour is not expected to occur. It is important to maintain close observations on stability of the earth fill when there is a tendency for the material to become saturated. Sometimes an earth-fill cofferdam is used to facilitate construction of a more permanent type of cofferdam behind it, as was done in the case of Hoover Dam. On some projects an earth-fill cofferdam may be developed by leaving some of the natural deposits in place, as was done at Madden Dam. In such cases it is essential to explore accurately the nature of the deposits and to determine the needs for sheet piling or some other form of seepage cutoff to stabilize the inner slope and minimize unwatering problems within the area.

Rock-fill Cofferdams.—Next in order of simplicity is the rock-fill type of cofferdam. This type of cofferdam merits consideration where a supply of rock is economically available as, for instance, from an excavation area such as a powerhouse substructure, where disposal to some point or other is required in any case. This occurred in one section of cofferdam at Wheeler Dam.

The rock-fill cofferdam can be constructed in more turbulent water which would wash away the ordinary earth fill. However, the rock fill requires some form of seal and at Wheeler Dam this consisted of a layer of clay deposited on the water side, with timber matting at the water line to protect the clay seal against wave wash. The chief precaution necessary with this type of

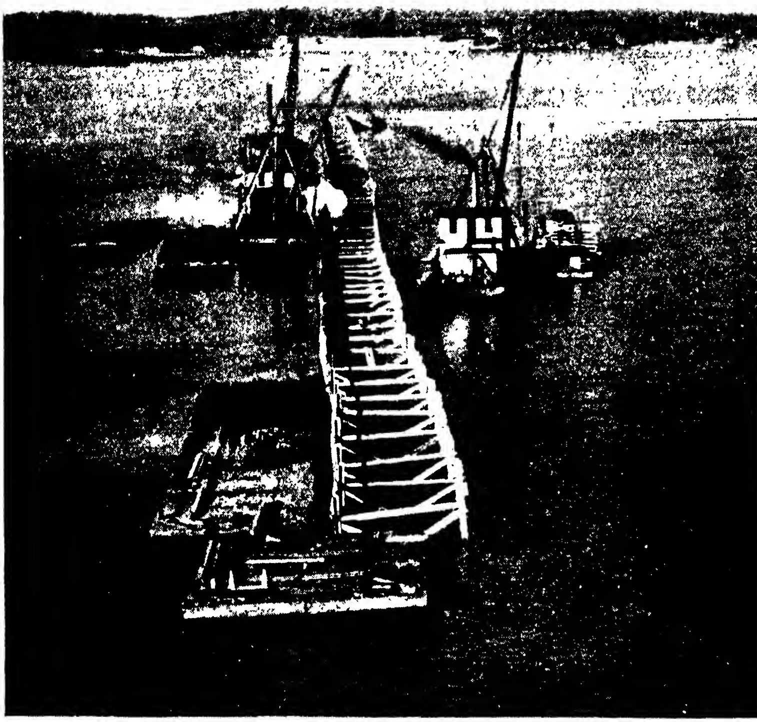


FIG. 25.—Ohio River-type cofferdam built at Wheeler Dam with floating plant. Derricks are dumping earth fill from barges into cofferdam.

cofferdam lies in determining the feasibility of making an effective seal, because with a poor seal it is, as a rule, difficult to locate the point of leakage and make adequate repairs after the cofferdam has been unwatered. This condition becomes even more serious on a porous foundation where the rock fill itself may be quite impervious but water is passing into the cofferdam through some of the rock fissures. Owing to the irregular face of the

rock fill and the tendency for large boulders to roll down and spread over a considerable area of the river bed, it is quite difficult to locate such leaks and to seal them effectively. Such sealing problems may, at times, cause enough delay in unwatering the cofferdam to consume most of the economies which may have been obtained from the cheaper initial construction.

Ohio River-type Cofferdam.—Figure 25 shows a cofferdam originally used on the Ohio River for relatively shallow water

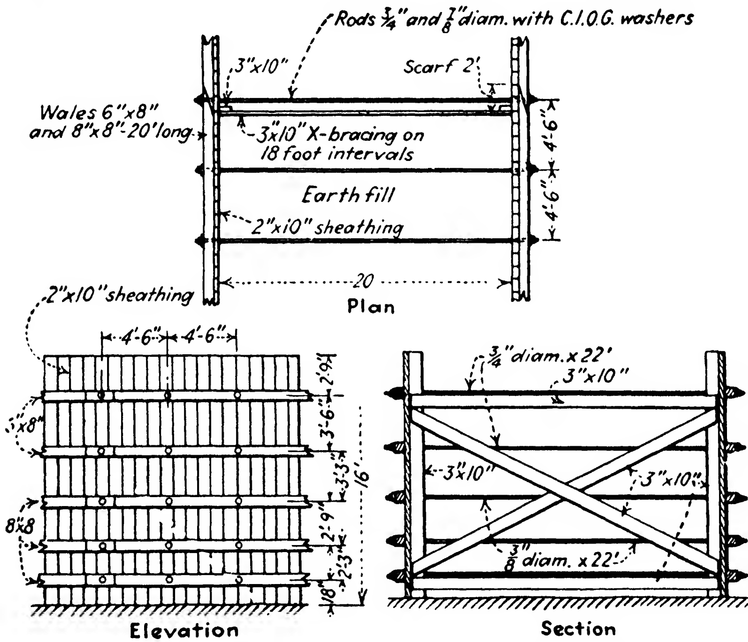


FIG. 26.—Design details of Ohio River-type cofferdam at Wheeler Dam.

and where the velocities are sufficiently low to permit this type of construction. Design details are shown in Fig. 26. This type of cofferdam is particularly economical for a height of 15 to 20 ft. because of its simplicity and the speed with which it may be constructed. The operations consist of assembling the frame members with suitable tie rods on a barge and making a continuous chain of these frames, which are lowered into the water successively as the framing proceeds. After the frame is in place vertical sheeting is installed, and the cofferdam is then ready for filling with clay or other impervious earth, which

provides adequate stability and a tight seal at the bottom. The important feature of this type is the need for low velocities in the river during construction to avoid overturning the timber structure before it is filled with earth. This type of cofferdam can withstand only a small amount of overtopping.

Rock-filled-crib Cofferdams.—For working in swifter water, and where greater height and the possibility of overtopping must be provided for, rock-filled cribs have found most popular application. Wherever possible it is desirable, first, to level off the bottom of the cofferdam site; otherwise, it is essential that the base of the crib be built so as to fit accurately any irregularities of the river bottom. It is common practice in the design of such cribs against sliding and overturning to make the width equal to the head of water which they must support. Other factors to be taken into account include internal shear, bursting pressure from within due to the fill material, and moment and shear in the walls themselves.

Such cribs can be of very economical design and construction, built up of poles obtained from clearing in the reservoir area. The customary procedure is to build the base of the crib on land or out on the dry and to shape the bottom to fit the rock contours which have been previously determined from soundings. This frame is then floated into its approximate position and additional timbers are built up on top until the bottom finally comes to rest on the rock. At this point a certain amount of rock may be dumped into the crib to help stabilize it, or the construction of the crib framing may continue to its ultimate height if there is no tendency for it to move away.

Watertightness may be developed either by dumping an earth fill against the water side, where there is no tendency to scour, or by lining a chamber of the crib with vertical sheathing, filling this with earth or clay and the remaining portion with rock. A third method of sealing rock-filled cribs, particularly when exposed to turbulent water, consists of facing the water side with a double layer of surfaced and tight-fitting planking.

The powerhouse cofferdam at Conowingo Dam consisted of a main row of rock-filled cribs which were designed for stability and a second row of cribs on the outside with sufficient space between the two to develop an intermediate chamber which was filled with clay. This type is especially suited to very rough

river bottoms where a wide band of clay is the most effective sealing medium. At the same time the clay chamber is protected from scour, and the design is economical in the use of impervious material where there is a scarcity of it.

Another interesting type of rock-filled crib can be built at a very high rate of speed with the aid of a locomotive crane. This

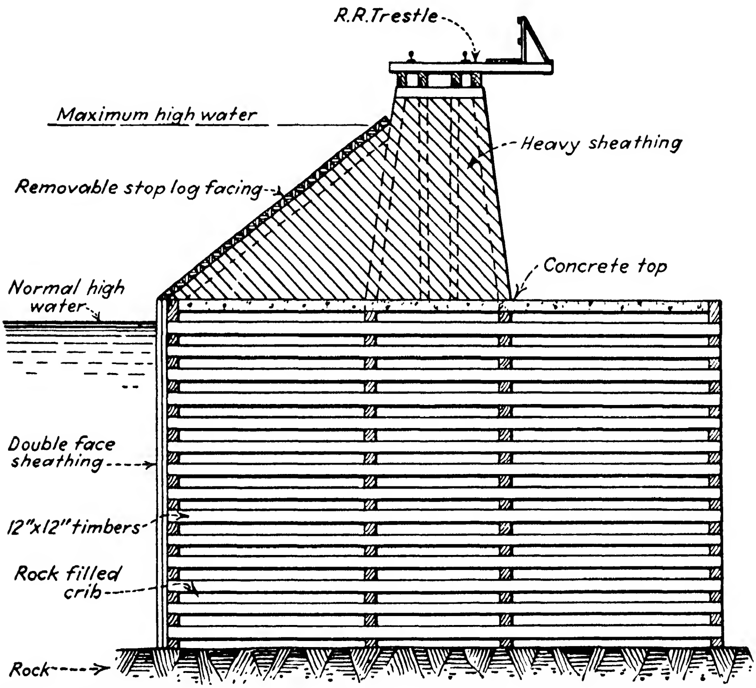


FIG. 27.—Crib cofferdam designed with provisions for overtopping at Chute-à-Caron Dam.

type was also used at Conowingo Dam and consisted of rock-filled cribs spaced about 10 ft. apart in order to gain distance in a minimum of time and also to avoid building up the head of water unnecessarily. With setting of these cribs going ahead, the next operation consisted of placing stop logs to span from crib to crib. Finally an earth fill was dumped against the outside to develop an effective seal. The same general principle was employed on the cofferdam which ran parallel to the direction of stream flow and was exposed to scouring action, by making a double row of staggered cribs and connecting each row of cribs

with stop logs on the inside and filling the resulting clay chamber with an impervious material for a seal.

A very economical type of rock-filled cofferdam was employed on the Chute-à-Caron Dam, in Canada. The problem in this case consisted of designing a crib which at times would be overtopped with a very heavy discharge, without letting the water rise above a given maximum level. Figure 27 shows the general features of the design, which was originated by C. P. Dunn. When the removable stop logs were in service, the weight of water on them helped to stabilize the crib. The stop logs rested against the trestle bents. These were covered with heavy sheathing to prevent the water from attacking the framing of the bents when it was spilling over the top.

TABLE 5.—DIMENSIONS OF IMPORTANT COFFERDAM CRIBS*

Item	Rock Island	Beauharnois	Dnieperstroy	Bonneville	Conowingo
1. Crib pocket size.	8 by 8 ft.	10 by 10 ft.	7 by 9.5 ft.	12 by 12 ft.	8 by 8 ft.
2. Maximum width of crib.	80 ft.	20 ft.	61 ft.	60 ft.	30 ft. (54 ft. including puddle chamber)
3. Maximum height of crib.	58 ft.	22 ft.	42 ft.	63 ft.	30 ft.
4. Vertical timbers.	12 by 12 in. in all outside corners	Bolted in outside corners	Scattering	8 by 12 in. bolted all outside corners of lower portion	Scattering
5. Principal timber sizes.	12 by 12 in.	8 by 8 in.	9 by 9 in.	10 by 12 in. 12 by 12 in.	10 by 12 in.
6. Timber lengths.	16 to 32 ft.	10 to 20 ft.	....	24 to 36 ft.	12, 16, 20, 24 ft.
7. Timber grade.	Douglas fir No. 1 & 2	B. C. fir	....	Douglas fir No. 2 common	Douglas fir

* This table includes data originally compiled by H. G. Gerdes.

Each local condition will have its own peculiar problems, and a judicious selection of the most economical type of crib construction can develop important savings in first cost. Table 5 shows principal dimensions of some of the most important crib cofferdams which have been constructed in the past.

The most recent of this group is the Bonneville cofferdam on the Columbia River, which was designed for an unprecedented height of 63 ft., the average height being 55 to 60 ft. A general

view of this cofferdam is shown in Fig. 28; particular note should be taken of the excellent fit obtained between the adjacent cribs, owing to the good sounding of the river bed and consequent accurate spotting of the cribs. The depth of water in which the cribs were sunk ranged from 30 to 50 ft., and the current averaged 7 miles per hour.

In the case of the Bonneville cofferdam the contractor was relieved of assuming responsibility for the major cofferdam

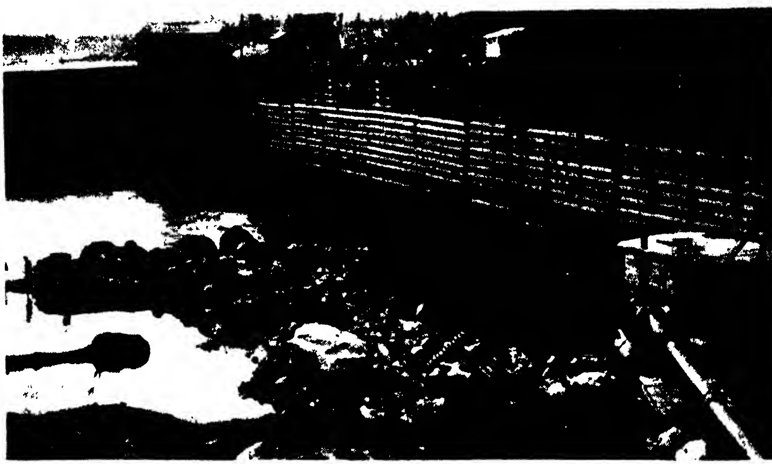


FIG. 28.—Inside of rock-filled crib cofferdam at Bonneville Dam on Columbia River built to record height of 63 ft.

hazards, for which he must usually include a rather high contingency reserve in his bid. The cofferdam was first studied on a model, and careful observations were made of various features, such as expected division of flow of the river during the first and second stages, direction of current and velocity, and scour on the bottom. The cribs contained weight pockets, which were filled with rock to sink them, and chambers lined with tongue-and-groove sheathing which were filled with impervious earth. Divers were employed to make a careful check of the contact at the base. In floating the cribs into place, control of their position was maintained by a system of cables which at times carried a load of 800 tons. This control system was quite ingenious, and its layout took full account of the shape of each crib and the proper point of application of holding lines so that the crib remained in a stable position at all times (see Chap. X).

A protecting face of steel sheet piling was driven so as to rest against the river side of the cofferdam and extend sufficiently down into the bottom to develop an effective seepage cutoff. An interesting feature of this steel facing was the presence of a series of T piles on 12-ft. centers. The object of these special T's was to permit the driving of a separate loop of piling along any point where unusual leakage or a break in the interlock or some other condition required the driving of a second line of piling. The T's provided a means for connecting this line to the main wall so as to form a continuous and effective water stop. This precaution proved very much worth while, as it became necessary to drive two or three such loops.

A further point of interest in the Bonneville cofferdam is that the cribs had an average deflection of 12 to 18 in. at the top after unwatering.

Concrete Wall Serving as Cofferdam.—Sometimes the use of mass concrete in an unreinforced gravity wall provides an advantageous type of cofferdam. This type of cofferdam has the advantage of occupying less base width than a rock-filled crib; where space is limited, this allows the development of more channel capacity for the diverted river. The wall can later be blasted with light shots and removed by ordinary excavating methods.

Steel Sheet-pile Cofferdams.—The details of various types of sheet piling and driving equipment are described in Chap. XI. The simplest type of sheet-pile cofferdam consists of an earth fill with a single wall through the center, the piling serving the dual purpose of developing a watertight cutoff and stabilizing the foundation and earth fill against destructive movements of water through such material. Special precautions are, of course, essential in the driving of such a wall to prevent localized leakage due to jumping the interlock. Single walls of piling also are occasionally used to face crib cofferdams for the purpose of developing a protective armor or reducing seepage. In considering such a cutoff it is important to balance its cost against the increased cost of pumping where a greater leakage is permissible.

In the construction of locks and dams on previous foundations on the upper Mississippi River and elsewhere, a double wall of sheet piling with an earth fill between the walls was used by a number of constructors. This type depends on a generous

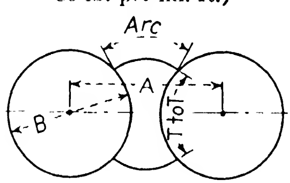
supply of horizontal tie rods and on the cantilever strength of the piling to keep the two walls tied together. There are a number of modifications of this general type, which include the use of walers on the outside and larger tie rods to develop a more economical design.

A novel type of sheet-pile cofferdam was developed by Lazarus White on the Mississippi River after making extensive studies of the seepage problems on models. It was found more economical to use only a single wall of steel piling on the river side and employ round timber piles with walers and timber sheathing on the inside for the purpose of retaining the sand fill. This gave much better seepage characteristics and permitted the fill between the walls to drain out more readily, instead of remaining in a saturated condition. It was also found that a careful location of the bottom of the outer cutoff wall, together with the proper slope of fill against the inside wall and a particular location of a trench at the toe of this fill would cause all the seepage to accumulate in the trench. This trench was located a number of feet below the ultimate working level within the cofferdam area, and connected to a sump from which all leakage was pumped out. By this method a dry cofferdam area was developed without the use of wellpoints or other special devices.

Cellular Sheet-pile Cofferdam.—The cellular cofferdam is probably the most difficult and expensive to construct but is frequently the most satisfactory type and of late has been employed on quite a number of projects. For large cofferdam jobs the advance driving of a small experimental cell is a good investment. By driving certain piles at different intensities and number of blows after reaching rock and then digging out inside the cell to gain access to the bottom, observations can be made of penetration and deformation of piling which will serve as a valuable guide in the construction of the main cofferdam. Pulling the piling in the experimental cell will furnish much valuable advance information on the problem of pulling the cofferdam, and permit making adequate preparations and development of necessary equipment for this work. Such a test cell, before and after being partly pulled up, offers ideal means for obtaining reliable data on ground-water flow, leakage through the cutoff wall, and an estimate of pumping requirements for the main cofferdam.

Some years ago the tendency was toward employing the diaphragm type of cellular cofferdam, with connecting arcs, but more recently this has been replaced by a line of cylindrical cells connected by short arcs. The chief advantage of the circular type is that each cell is independently stable and this permits construction at various points. The filling and, later, the removal, of each cell can be performed at the most convenient time and independently of the adjacent one. This is not the case with the diaphragm type, where 8 or 10 cells must be filled or emptied simultaneously and in stages to prevent distortion of the diaphragms. Although for the lower cofferdams less steel is required with diaphragm types, this principle does not hold true in the case of high ones, of 50 to 55 ft. Considering the difficulties of construction and removal with the diaphragm

Table 6.—Design Data for Cellular Steel Cofferdams
(For flat-web piling section, 15- by 3/8-in. web, 38.8 lb. per lin. ft.; tees, 80 lb. per lin. ft.)



Height of cofferdam, feet	*B* Diameter of cells, feet	*A* Spacing of cells, center to center, feet	Number of piles: In cell, total	Number of piles: In arc	Number of piles: T to T	Tons of piling per linear foot of cofferdam "A"*
30	35.014	40.041	88	8	16	1.379
32	36.606	40.377	92	8	18	1.518
34	38.197	42.299	96	8	18	1.610
36	39.789	42.624	100	8	20	1.754
38	42.972	46.462	108	8	20	1.823
40	44.563	48.345	112	8	20	1.920
42	46.154	50.208	116	8	20	2.012
44	47.746	50.617	120	8	22	2.155
46	50.929	56.728	128	10	22	2.196
48	52.521	57.136	132	10	24	2.340
50	54.112	59.009	136	10	24	2.432
52	55.704	59.404	140	10	26	2.577

* For actual requirements add 10 per cent to cover field irregularities.

type, it is, in the majority of cases, more economical to use additional steel and to construct the circular type. Table 6 gives general design data for this type, prepared by R. T. Colburn.

Pile-driving Templet.—It is usually necessary with the diaphragm type to leave most of the timber framing, which serves as a temporary support and templet for the steel, in place for a group of 10 or 12 cells until they are filled to a point of stability, and this again is an uneconomical use of materials as compared with the circular type. This was demonstrated

Fig. 29.—Building cellular steel cofferdam at Pickwick Landing Dam. Portable steel templet used to assemble cells.

to an unusual degree at Pickwick Landing Dam where James E. Walters devised a new type of portable steel templet consisting of pipes and a cable-bracing system as shown in Fig. 29. This templet was 58 ft. in diameter and 20 ft. high and was very rigid and easy to handle. It was equipped with steel pipe spuds, spaced at four points on the templet; these were lowered down to the river bottom to serve as supports for the templet.

The templet itself was located at the proper distance from the adjacent cell by means of short spacer struts. Two platforms built into the templet were particularly handy for the pile-driving crew in gaining access to important points along the cells for guiding the piling during the assembly. The spacing of the piles was carefully marked on both the top and bottom

walkways to indicate readily how the assembly was progressing and assure proper fit of the final pile.

With this system the templet was reused immediately after the cell was driven, and this was the major element of economy. It took approximately 4 hr. to reset the templet, and the total time required for a templet setting, assembly of sheet piling, and driving through a 10- to 15-ft. layer of gravel to rock required an average of 18.33 hr. per cell.

The Pickwick cofferdam consisted of 26 cells 59 ft. in diameter and 61 ft. 8 in. center-to-center spacing. The piling was 15-in., 38.8 lb. per lineal foot, Section SP 6 flat-web sheet piling. Although in the design of these cells the interlock strength was limited to 9,000 lb. per lineal inch, the piling actually developed under a test a breaking strength in the interlock of 20,000 to 30,000 lb. per lineal inch. The piling was driven by means of two 8-ton, 110-ft. boom skid derricks, mounted on barges, and two 9-B-3 McKiernan-Terry hammers, delivering 145 strokes per minute. The entire cofferdam of 26 cells was driven within 28 days, including holidays.

A special consideration in the design of this cofferdam was the use of sufficient piles in the short connecting arcs. Ten piles were used at each side, and these were sufficient to adjust themselves as they were driven to rock and take up irregularities in parallel alignment between the two adjacent cells. Another important feature of this cofferdam is the fact that not all piling is at the same level at the top. For economy in steel the top of the outer wall extends 5 ft. above the inner wall and acts as a cantilever; the cross walls are shorter than both walls.

The most important principle in driving such a sheet pile cofferdam is to *keep all piling vertical at all times.*

The Pickwick system, with the simple type of portable templet, can be used under higher river velocities, provided a more rigid type of templet is employed. When it comes to final closures in a channel it may be necessary first to divert the river before the last few cells are placed, either by means of an earth fill or rock fill or cribs because, as a rule, the open water is too swift to permit satisfactory assembly of the cells.

Sandbagging.—It is a tradition that the big floods come down the river when a dam is being built on it. If the cofferdams are high enough for ordinary floods it is likely that the water

will come very near the point of overtopping, and when this appears imminent there is feverish activity at all points to pile up sand bags to hold back the last foot or two of the flood rise. For such cases a generous supply of bags, say 5,000 or 10,000, available on a moment's notice, is an essential part of a fully equipped cofferdam layout.

CHAPTER X

DIVERSION OF RIVERS AND FINAL CLOSURE

Diversion Tubes and Channels.—Diversion of the river out of its natural bed is generally the most important and most critical operation in the construction of a dam. In the case of wide rivers, cofferdamming has normally proceeded from one or both sides, and the structures built within these cofferdams contain notches or diversion tubes designed to carry the river during the period when construction is under way in the remaining portion of the natural bed.

In the case of narrow canyon projects, the customary procedure is first to build tunnels parallel to the river around the site of the dam. A barrier is then thrown across the river above the dam site and the water is diverted through these tunnels. A similar barrier near the downstream end of the tunnel closes off the dam site so it may be unwatered and construction can proceed thereafter without interruption. The best known project employing this method is Hoover Dam. A similar procedure has been used on a number of large Western projects such as Owyhee, Baker River, Parker, Skagit and others. In the case of Hoover Dam the importance of the diversion barrier, or dam, near the upstream end of the tunnel was sufficiently great to justify special preparation of its foundation.

The design of adequate capacities for the diversion channels, together with their necessary diversion cofferdams, involves major problems of construction economics. Where the construction is carefully timed, so that uncovering of the foundation occurs during the low-water season when river-handling problems are reduced to a minimum, important economies are possible, as, for example, in the case of Horse Mesa Dam. Here a timber flume carried the low-water discharge over the construction area until it was possible to raise the concrete structure to a point where larger passageways through the dam could handle the larger floods. Such flumes are particularly economical where the discharge is less than 1,000 sec.-ft.

In many cases the river is too large to be handled by a flume, and it is then customary to leave the river in its bed until the adjacent structures have been built up and provided with adequate openings to carry the diverted river. These openings or diversion tubes sometimes require very careful design and study of their discharge capacities on a hydraulic model. This applies particularly to projects where space is limited and every effort must be made to develop a high efficiency of discharge. Under low efficiency it follows that the head must be correspondingly

FIG. 30.—Streamlining of inlet of temporary diversion tunnel at Calderwood Dam increased the discharge capacity 15 to 20 per cent over square-faced inlet.

greater to pass a given quantity of water, and when this head is considered in building the diversion cofferdam it is at once obvious that the increased height of this cofferdam, together with the greater difficulty of closing the channel, means a substantial increase in cost of diversion.

Figure 30 shows the inlet of a properly designed diversion tube. The specially formed concrete bellmouth inlet increased the capacity of this diversion tube approximately 15 per cent over the ordinary square-edged inlet and resulted in a substantial reduction in head on the adjacent cofferdam. This process of increasing the discharge capacity is generally cheaper than enlarging the diversion tubes, because of the greater cost of closure gates and filling operations for the larger openings.

Sometimes it is necessary to provide special diversion channels for large discharges, as, for example, 75,000 sec.-ft. at Madden Dam. The river passed through the diversion channel during the low-water season just before steps were taken to close the dam. Short extensions of the draft-tube piers of the powerhouse substructure projected above the water level. These piers contained stop log grooves which were used to close off the downstream end of the channel, thereby saving the cost of a temporary cofferdam. At the upstream end a series of rock-filled cribs were lowered into place, after which construction was carried on within this former channel area.

A further example is the diversion channel left in one section of the dam at Bingham, Maine. This channel had intermediate piers to reduce the span of the closure gates, which were later lowered across the inlet to cut off the discharge and direct the water into other controllable passageways while the placing of concrete was under way in this channel.

In the case of extremely wide rivers as, for example, the Tennessee, with discharges ranging up to 250,000 sec.-ft., it is necessary to provide extensive passageways for the large floods as in the case of Wheeler Dam. Here the water was directed through notches left in the partly completed section of the dam while another section of the dam was under construction. The floor of these notches was above tail water and above the floor of the intake structure in the powerhouse section. This intake structure was designed for the future addition of generating units but during the latter stages of construction carried the river. At low stages the water was all carried by the intakes, and the notches were exposed so that concreting from floating mixing plants proceeded without interference except for one small group of notches which were closed off by a special type of structural-steel form lowered against the upstream face of the dam.

The use of the permanent passageways through the dam to carry the water during construction can often lead to substantial economies.

Methods of Diverting Rivers.—Probably the most spectacular phase in the construction of the dam occurs when the river is diverted out of its old bed and is forced to accept temporarily

a man-made course before it is finally converted forever into a tranquil lake upon completion of the dam.

One of the simplest methods of diverting a river is by means of an earth-dam plug, as employed by R. M. Conner in diverting the Chagres River at Madden Dam. This closure is shown in Fig. 31. A part of the river was already passing through the diversion channel whose bottom was sufficiently low to avoid the necessity of raising the water very much in making diversion. Combined with this feature was an unusually low stage of river

FIG. 31.—Diverting Chagres River during low-water season by earth fill placed by dragline.

discharge, but in spite of this it required many hours of feeding boulders and dirt into the gap before the river finally yielded and permitted itself to be choked off. Once the river was diverted, it was a simple matter to construct a crib cofferdam at the downstream end. These cribs were set directly on the gravel bottom, and a steel sheet-pile seepage cutoff was driven along the face of the cribs extending down to rock. With this diversion completed, the river section was unwatered, and construction of the main dam proceeded without delay.

The real fight on a river occurs when the construction has developed a substantial head through the remaining open section, and in many cases the water is too swift for any earth or small stones to remain in place. In such cases, it is necessary to use large rocks and boulders and build a rock-fill barrier which

has sufficient stability to choke off the water. This method was employed by G. P. Jessup at Wheeler Dam. After this barrier had been substantially sealed off with smaller gravel and earth, an Ohio River type of watertight cofferdam was constructed behind it to provide an effective seal across the last section of the river bed. In general, it is feasible to divert by

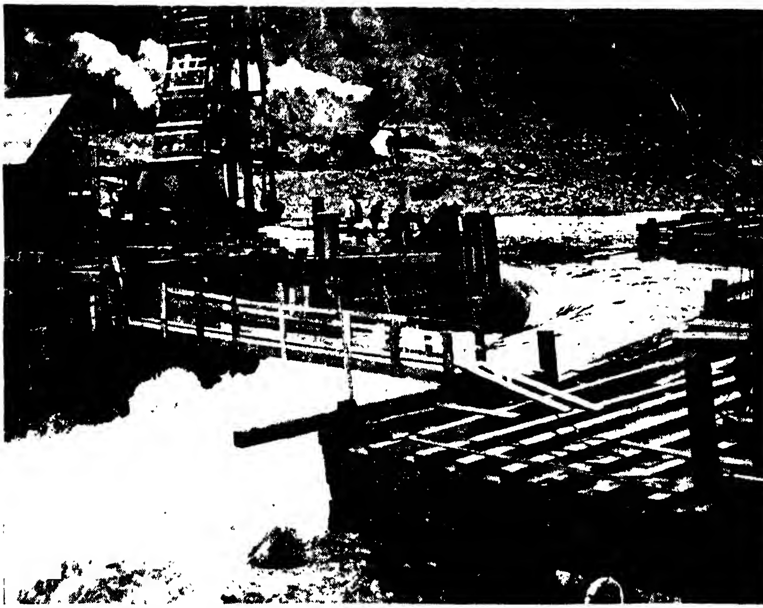


FIG. 32.—Closure crib being floated into place for Rock Island Dam cofferdam on Columbia River.

means of earth or a combination of earth and rock against heads of 1 or 2 ft. and by means of heavy rock fills against heads of 2 to 4 ft.

When it comes to choking off the discharge, particularly in the last sections of a barrier under heads of 4 to 5 ft., or greater, the rock-filled crib is usually the most common expedient where the river bottom is solid rock or of a material sufficiently stable to support heavy cribs without undermining them. In the case of such rock-filled cribs the last one or two cribs must usually be placed with very reliable control by means of cables anchored to the shore and to other points upstream from the working area. Among the most difficult crib-handling jobs were the ones employed on the Columbia River at Rock Island Dam (Fig. 32)

and more recently on Bonneville Dam. Figure 33 shows a general plan of holding lines employed on the cribs at Bonneville.

Turning a River in Michigan.—An interesting experience occurred in the soft river bed of the Hodenpyl project on the Manistee River in Michigan, built by the late E. M. Burd. "Turning the river" was a keenly anticipated event in which every man on the job lent a hand. Preparatory work included the driving of a system of timber piling across the river together

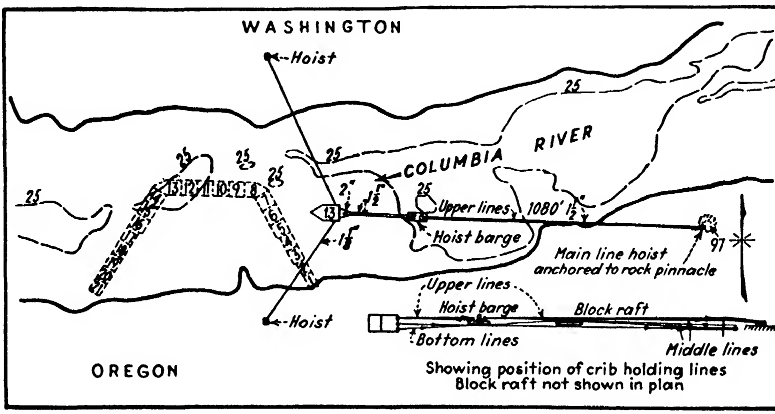


FIG. 33.—General plan of holding lines for placing cofferdam cribs at Bonneville Dam.

with a steel and Wakefield pile cutoff in the river bed extending only a few inches above the bottom to form an effective stop against undermining of the diversion structure. A plentiful supply of poles was placed near this barrier, and bundles of evergreen brush about the size of a bushel basket were made up in large quantities. A system of metal chutes and one or two hydraulic giants for washing down sand into the barrier structure were placed in readiness.

On the eventful day the barrier structure was alive with men carrying poles and bundles of brush and depositing them in alternate layers between the rows of piling. The sand was washed down into this mass, and slowly but surely the river was choked off and effectively sealed, thereby forcing it into a new channel. This channel led the water into special spillway tubes through which the river was permitted to pass until the reservoir was ready for impounding, at which time the gates at the upstream end of the tubes were lowered into place.

Saguenay River Diversion Most Difficult in History.—Probably the most difficult river diversions ever attempted were made on the Saguenay River in Northern Quebec, Canada. The first one occurred in 1924 in connection with the construction of Ile Maligne Dam by F. H. Cothran. This river has a normal low-water discharge of 25,000 sec.-ft. (15,000 sec.-ft. minimum) and at flood times exceeds 225,000 sec.-ft. The bed is solid granite, and the river is virtually a series of rapids, with velocities in places reaching 30 ft. per sec. Construction of the diversion barrier was planned for a stretch of comparatively quiet water, and a heavy rock fill was built out into the river three-fourths of the way with satisfactory results. This rock fill extended a considerable distance up and down stream and was formed by side-dumping from railroad cars, the track being shifted outward as the fill progressed.

Eventually, however, the water became so swift that it was impossible to hold the material. Huge boulders dropped into the constricted channel were carried away as though they were logs. Fifteen-ton rocks tied together with steel cables disappeared in the turbulent water. Steel cables 1 in. in diameter, attached to structural-steel cribs built up of heavy I-beams, broke like strings. Blocks of concrete which were dumped into the water did not settle down to choke the channel, as was expected, but were carried off and deposited on the bottom a considerable distance down the river.

The fight with the river was temporarily suspended while an entirely new line of attack was developed. It consisted of building near the uncompleted section of the barrier a diversion channel parallel to the river and deep enough to draw the water automatically into it once the inlet had been opened. The diversion channel was 125 ft. wide by 500 ft. long and varied in depth from 25 to 40 ft. Of this length, 320 ft. of channel was excavated by steam shovel, leaving solid rock dikes at each end which were later blasted away when everything was in readiness. In the center portion of the channel, concrete piers were constructed with grooves for supporting closure gates, which offered a simple means of stopping the water whenever desired.

The most spectacular feature of this work was the necessity of blasting away the upstream and downstream dikes, or bulkheads, so thoroughly that none of the rock remained in place.

The new channel was thus created within a few moments. The upstream dike contained 14,700 cu. yd. of rock, and the downstream one 17,500 cu. yd. Two months were required to dig nine tunnels under these dikes at various locations. These tunnels were heavily loaded with dynamite, 205,000 lb. of explosives being used, or an equivalent of about 6 lb. per cu. yd. of rock. The eventful blast threw away both dikes and scattered them upward approximately 1,500 to 2,000 ft. and deposited them within a radius of ¼ mile. Less than 5 per cent of the blasted rock fell back into the channel.

In order to protect the concrete piers, midway between the two dikes, 35,000 cu. yd. of sand had been dumped around them and filled to a distance of 8 ft. over the top to absorb most of the shock from the blast and to prevent destructive cracking or displacement of the piers. The sand was very effective in preventing damage, and after a jet of water had washed a hole through the sandbank the 35,000 cu. yd. of sand was washed away by the river running 26,000 cu. ft. per sec., in 25 min. With most of the river passing through the new channel, it was then a simple matter to choke off the remaining flow in the old river bed. With this flow cut off, closure gates were lowered between the concrete piers to complete the cutoff and accomplish the desired diversion of the river.

Obelisk for Diversion of Saguenay River.—In 1930 the Saguenay River was diverted for a second time at the Chute-à-Caron project. At the point where the main dam crossed the gorge the water was 65 ft. deep at low discharge. At this site the water falls very rapidly and a deep tailrace was excavated to develop the full head of water available at the site for power. This tailrace automatically formed the lower half of a diversion channel. A special sluiceway was constructed under the powerhouse section to carry the river temporarily from the upstream diversion channel into the tailrace.

Construction of the diversion channel and tailrace involved the excavation of 700,000 cu. yd. of earth and 500,000 cu. yd. of rock. The channel was designed to carry 50,000 sec.-ft.; the two sluice tubes under the powerhouse could be closed by means of two gates, each 20 by 40 ft.

The most spectacular feature of the project was the method of diverting the river out of its natural bed into the new channel.

Having in mind the difficulties experienced at Ile Maligne, the engineer centered his efforts on devising an entirely new method of closure. The bold scheme finally projected by James W. Rickey contemplated the equivalent of building a dam on end on the dry shore and at the desired time blasting away a portion of its supporting pedestal so as to cause this huge structure to tip into the river and come to rest at the desired point of diversion.

The name given this unusual structure in its earliest conception was "obelisk." Since nothing like this had ever been attempted before, practically no design data were available, and numerous studies were made on motion pictures of falling chimneys and small blocks of wood, together with comprehensive mathematical analyses of the mechanics of falling bodies. Eventually a hydraulic model was built of the river and diversion channel, together with the obelisk and related structures. This was thoroughly tested and resulted in the development of experimental data and a theory regarding the cushioning power of water. It was found that no cushioning materials would have to be constructed on the face of the structure, and that the obelisk would not skip over the water or move downstream before coming to rest. In fact every assurance was developed in advance that the obelisk would land in its designated position.

Soundings had been made of the entire river bed at the site of the obelisk, and owing to the high velocity of the water—up to 30 ft. per sec.—this was an exceedingly difficult job. These soundings provided the design data for developing a contoured face on the obelisk which conformed to the shape of the river bed. As finally constructed, the obelisk was 92 ft. high, 45 ft. wide, and 40 ft. at its maximum depth. It contained 5,400 cu. yd. of concrete, weighed 11,000 tons, and was heavily reinforced with steel rods and cables.

It was successfully tipped on July 23, 1930, creating the largest man-made splash in history, in a remarkable setting of thrilled spectators who had come from afar as well as from the near-by countryside, lining the hills on both sides of the river to witness this spectacle. The obelisk landed within 1 in. of its designated position. Once in place, it took only 72 hr. to seal the opening at each end and dump rock and gravel along the upstream face until all leakage had been successfully cut off.

Making Closures in a Dam.—A combination of diversion and preliminary closure is sometimes used, as was employed by Ross White and F. C. Schlemmer at Norris Dam, which is illustrated in Fig. 34 The same system was also used on Conowingo and Safe Harbor dams. Such partial closures are made where the

FIG. 34.—Lowering 60-ft. wide diversion gate in front of low block on Norris Dam.

river has been temporarily passing through low blocks in the dam and the work has reached the stage where it is necessary to raise these blocks. For this purpose a special steel frame or gate is provided, which at Norris Dam was 60 ft. long; because of this great span, intermediate cantilever columns were embedded in the concrete to help support the gate.

The gate was handled by an overhead cableway and lowered down in front of an open block until it cut off the water, after

which it was rigidly anchored into place and fully sealed by inflating a rubber hose embedded along the edges of the gate. Thereafter, concreting proceeded behind the gate for a new lift of 5 ft. In the meantime, the water was directed over one of the adjacent blocks, which was about one-half of the height of the gate lower in elevation than the top of the block being concreted. After the concrete had hardened in this block the gate was transferred to the other one, and the water cut off there and thrown back over the newly formed level of the first block, while an additional lift was placed behind the gate in its new position. In this manner the water was thrown from one block to the other and back again until enough head had been developed to pass the river through permanent sluiceways located in the body of the dam. For final closure it was only necessary to close the gates in these sluiceways.

Closure with Sheet-pile Portal Gate.—A novel form of closure was developed by Lazarus White on Lock and Dam No. 6 on the Mississippi River. The contractor on this project had originally constructed the locks located on the Wisconsin side of the river and was subsequently awarded the contract for the dam for which the construction procedure required building the first half on the Minnesota side, then diverting the river to the completed section and subsequently building the remaining half of the dam on the Wisconsin side. The contractors decided to use the same concrete plant and other facilities that had been employed on the locks and gain access to the cofferdam on the other side of the river by means of a construction trestle. This trestle was so located that its downstream face coincided with the outer face of the final stage cofferdam. The line of sheet piling was placed against the face of the trestle.

The unusual feature on this project was the closure gate, or "portcullis" 42 ft. wide and built up of steel sheet piling about 45 ft. long. After the line of piling had been driven to grade on each side of the closure gate, and slightly overlapping the gate, final closure was made by lowering the gate, which was suspended from a timber frame. There were two important features on this closure gate: One was a waler tied to the lower edge of the gate which kept the piling from being deflected downstream by the water, the waler sliding along timber piles which had been driven in preparation for the closure to carry the thrust on the

gate. The other noteworthy point was that the closure gate was located on the downstream side of the trestle; this location prevented severe turbulence at the outlet from undermining the trestle.

Closure by Means of Segmental Arch Rings.—A novel method of closure which is destined to greater application in the future was employed on the Krangede Dam in Sweden and was described in *The Engineer* of London, March 20, 1936. The problem

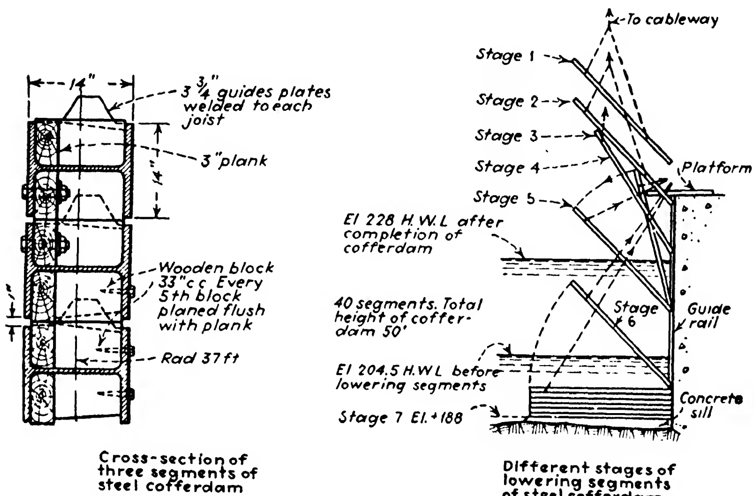


FIG. 35.—Segmental arch ring closure on Krangede Dam in Sweden, showing timber seal (at left) and guide rails (at right).

consisted of closing two openings, each 66 ft. wide, against a total head, after closure was completed, of 40 ft. The sketch in Fig. 35 shows the general method. Each segment consisted essentially of a 14- by 14-in. H beam which was first cut in half at the center of the web, after which the flanges were bent to a radius of approximately 37 ft. and the two parts then welded together. A timber seal was bolted to the upstream side as shown in Fig. 35. The two ends of these segments were arranged to slide along guide rails along the face of the dam. The actual closure took about as many days to build as an ordinary operation would have required in months.

This system might be used to advantage for periodic unwatering of the upstream face of a dam for inspection purposes if it is

originally equipped with a system of guide rails to support the ends of the segments.

A modification of this idea was used by Frank Crowe in 1938 to close the diversion tunnel at Parker Dam by lowering over the inlet an upturned section of the cylindrical steel form which had previously been used to place the concrete tunnel lining.

Final Closure Gates for Filling Reservoirs.—A special type of closure gate on rollers was employed on Diablo Dam to shut off the temporary openings which carried the water during con-

FIG. 36.—Flap gates on Alcona Dam powerhouse ready to be dropped, with three already down. Note tremie chutes for placing concrete plug behind gates.

struction. A special sliding gate was also built on the job for a similar purpose at Coolidge Dam. This gate was sufficiently heavy to assure closure and support a large head of water before the passageway behind it through the dam was filled with concrete. At Dix River Dam a special type of hemispherical steel gate was employed because of the unusually large opening. It operated in the form of a hinged gate supported at the top and lowered down in front of the opening on the day of closure.

Figure 36 shows a simple type of flap gate at Alcona Dam, normally stored in a vertical open position and dropped into place by cutting the supporting wires when the reservoir was ready for impounding. These gates were of very simple construction of a combination of I beams and timbers, and, contrary

to expectation, such gates do not slam shut with an impact but merely drop in the water, which carries them against their seat at slightly higher velocity than the water itself had while passing through the openings. As soon as these gates were in place the space behind them for a limited distance was filled with concrete through the tremie chutes shown in the photograph.

CHAPTER XI

PILE-DRIVING AND EXTRACTING EQUIPMENT

American sheet piling has become standardized with respect to the design of interlocks so that the differences are only minor, as indicated in Fig. 37. It is possible to interlock the sheet

EFFECTIVE WIDTH	AREA IN □ INS	WEB THICKNESS	WT/FT OF PILE	WT/□FT OF WALL	SECT MOD PER BAR INS³	SECT MOD /LIN FT OF WALL-INS³	MOM INERTIA INS⁴	MIN INTERLOCK STRENGTH PER LIN. IN.	ULT TENSILE STRENGTH PER □ IN	STANDARDIZED DEFLECTION
15"	11.41	$\frac{3}{8}$"	38.8#	31.0#	3.7	3.0	6.0	12,000#	70,000#	10°

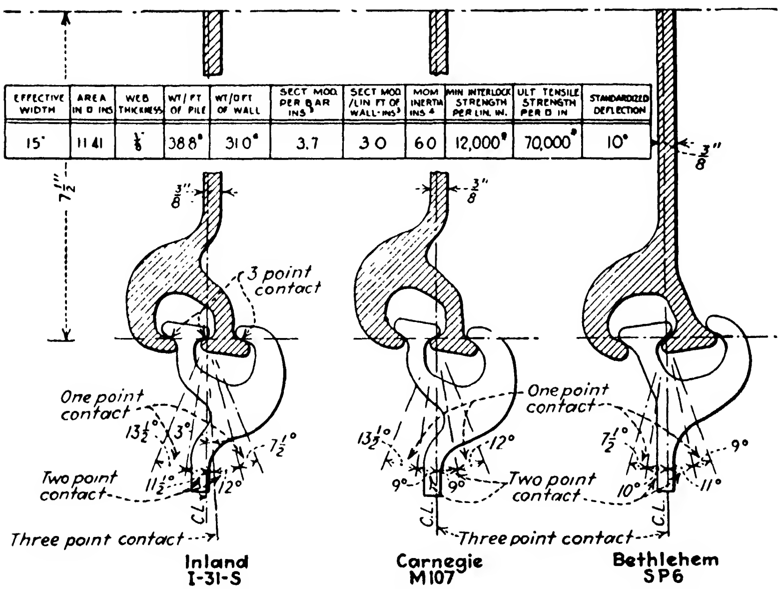
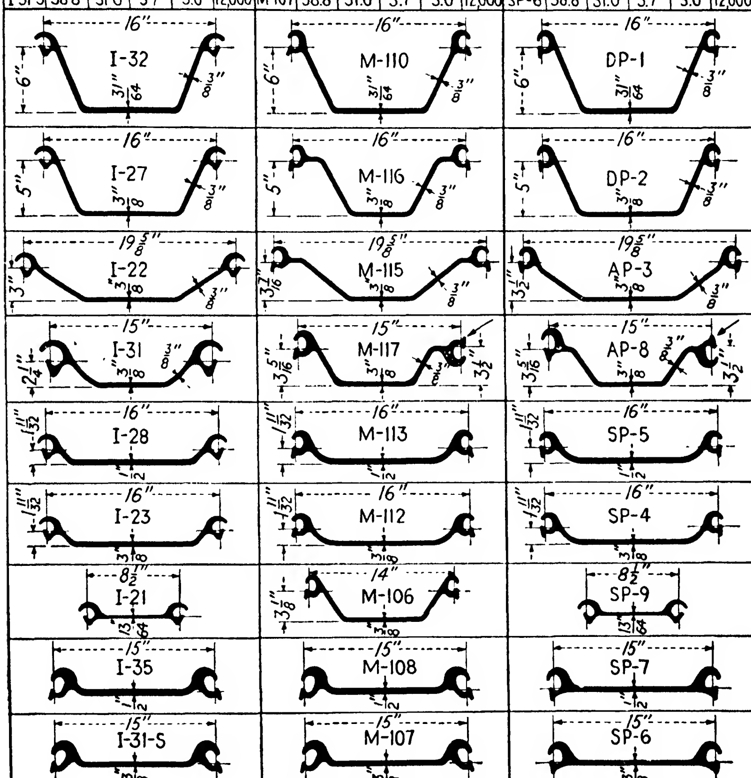


FIG. 37.—Typical interlocks on three standard makes of sheet piling.

piling of different makes, but this is not advocated where the stress is likely to be high, because a combination of different interlocks may develop eccentricities which might overstress one or the other. Table 7 gives the dimensions and properties of the more common types of sheet piling. Recently additional pile sections were placed on the market known as Weirton WS1, WS2, WS3, and WS4, corresponding to Carnegie sections M107, M108, M112 and M113 except that WS1 and WS2 are about 10 per cent lighter in weight.

TABLE 7.—STANDARD STEEL SHEET PILING SECTIONS PRODUCED IN THE UNITED STATES

Inland Steel Co. *						Carnegie Illinois Steel Co. (Pitts.) * †						Bethlehem Steel Corp. *					
Sections	Weight Per Foot	Weight Per sq. ft. Wall	Section Modulus	S.M. Per Lin. Ft. Wall	Interlock Strength Per Inch	Sections	Weight Per Foot	Weight Per sq. ft. Wall	Section Modulus	S.M. Per Lin. Ft. Wall	Interlock Strength Per Inch	Sections	Weight Per Foot	Weight Per sq. ft. Wall	Section Modulus	S.M. Per Lin. Ft. Wall	Interlock Strength Per Inch
I-32	42.7	32.0	20.4	15.3	8,000	M-110	42.7	32.0	20.4	15.3	8,000	DP-1	42.7	32.0	20.4	15.3	8,000
I-27	36.0	27.0	14.3	10.7	8,000	M-116	36.0	27.0	14.3	10.7	8,000	DP-2	36.0	27.0	14.3	10.7	8,000
I-22	36.0	22.0	8.8	5.4	8,000	M-115	36.0	22.0	8.8	5.4	8,000	AP-3	36.0	22.0	8.8	5.4	8,000
I-31	38.8	31.0	8.1	6.5	10,000	M-117	38.8	31.0	8.9	7.1	10,000	AP-8	38.8	31.0	8.9	7.1	10,000
I-28	37.3	28.0	3.3	2.5	12,000	M-113	37.3	28.0	3.3	2.5	12,000	SP-5	37.3	28.0	3.3	2.5	12,000
I-23	30.7	23.0	3.2	2.4	12,000	M-112	30.7	23.0	3.2	2.4	12,000	SP-4	30.7	23.0	3.2	2.4	12,000
I-21	14.9	21.0	1.0	1.4	8,000	M-106	36.2	31.0	10.3	8.9	10,000	SP-9	14.9	21.0	1.0	1.4	8,000
I-35	43.8	35.0	3.8	3.1	12,000	M-108	43.8	35.0	3.8	3.1	12,000	SP-7	43.8	35.0	3.8	3.1	12,000
I-31-S	38.8	31.0	3.7	3.0	12,000	M-107	38.8	31.0	3.7	3.0	12,000	SP-6	38.8	31.0	3.7	3.0	12,000



† Z-Sections not shown

* *Interlock strength, direct tension, lb, per lineal inch.*
Section modulus per lineal ft. of wall interlocked-24.5 for Sections I-32, M-110, DP-1

For cellular cofferdams, where the piling is in heavy tension through the interlock, a straight-webbed piling is generally employed, and special T's and Y's are fabricated for the junctures. The piling usually has two handling holes at the top which are later used for extracting. Important economies can be developed by properly arranging with the fabricator to schedule his shipments so that the piling can be handled almost directly from cars into the work. It is a great advantage to have the length of piling marked at the rolling mills, either by stencils or dies, to facilitate handling in the field.

It should be noted that the angular relationships of interlocks shown in Fig. 37 are subject to variation of one or more degrees due to rolling tolerances, and are not necessarily representative differences between makes of piling. Furthermore, the rolling of the interlocks can be modified to meet special conditions, as in the case of the 90 ft. long piling for the Kentucky Dam cofferdam where the fabricators agreed to furnish a guaranteed interlock strength of 16,000 lb. per lin. in., thereby introducing a substantial economy in cofferdam design. The ultimate strength of interlock on heavy straight-webbed piling ranges between 24,000 to 30,000 lb. per linear in.

Pile Drivers.—The best manner of handling sheet piling for driving in cofferdams or other structures depends largely on local conditions and the availability of equipment which may be suited to other services after the driving is completed. With certain hammers, and where the piling is exceptionally long, say greater than 60 ft., or the penetration is difficult, it is customary to handle it in special leads where it may be braced against lateral deflections. In the construction of cofferdams it has become quite common to dispense with leads and use a suitable yoke or guiding fins on the bottom of the pile hammer so that it can rest directly on the pile and keep the hammer in a vertical position.

Figure 38 shows two common types of leads. They are sufficiently long so the longest piece of piling may be readily handled and passed over obstructions, and with sufficient space to spare at the top to accommodate the hammer and rigging. The hoisting equipment on pile drivers is generally steam operated because steam is also required on the hammers and later on the extractors; this usually requires oversized boilers

because of the great amount of steam which is sometimes needed during difficult extracting.

At Pickwick Landing Dam, as described in Chap. IX, the pile-handling equipment consisted of special skid-guy derricks, which normally operated on land but were later mounted on barges and floated for the construction of the cellular cofferdams.

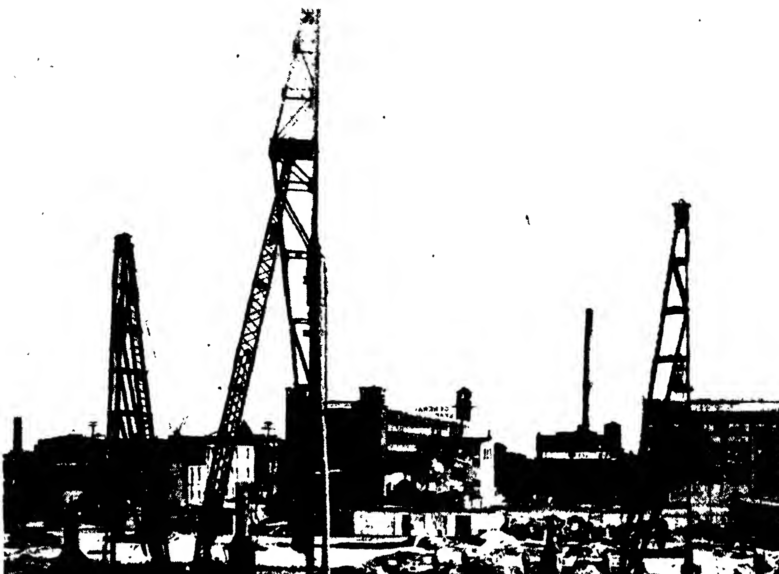


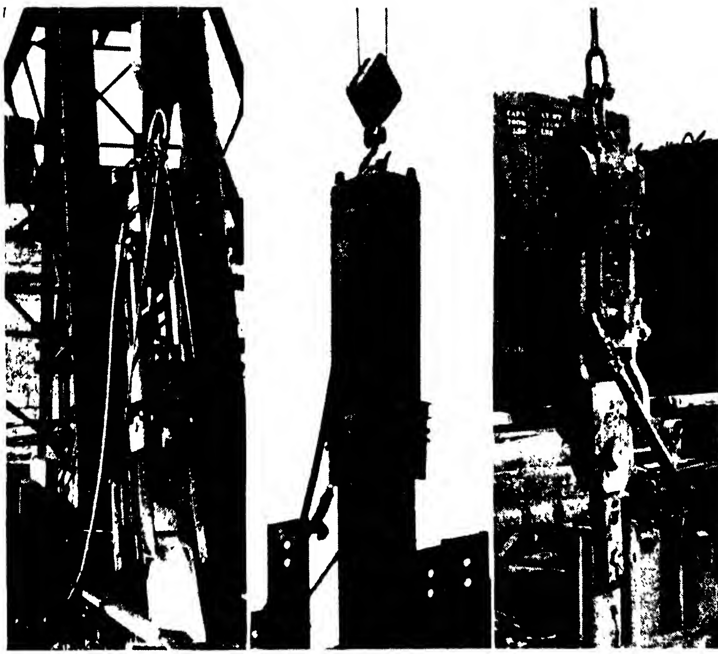
FIG. 38.—Typical pile-driving leads. At left, swinging leads mounted on crawler crane; at right, fixed leads on skids with steam hoist.

Special attention must be given to the mobility of the equipment in shifting or booming from pile to pile, as a great amount of time may be lost by cumbersome equipment.

Pile Hammers.—Typical American pile hammers are shown in Fig. 39, and their characteristics for the heavy-duty sizes are given in Table 8. The selection of a pile hammer should take account of the following fundamental considerations:

1. The ram must be of the proper weight in relationship to the weight of the pile and the resistance to penetration.

2. The velocity of the ram at the instant of striking should be low A transfer of energy at low velocity moves the pile farther. If the ram is too light it will rebound and barely overcome the inertia of the pile. If the ram is too heavy it may bend or otherwise damage the pile. If the velocity is high, rebound and battering of the top will develop. The efficiency of transferring energy from hammer to pile in such cases is low.



(a) (b) (c)

FIG. 39.—(a) Single-acting pile hammer mounted in inclined leads; (b) double-acting hammer; (c) pile extractor.

The energy developed by a pile hammer, in foot-pounds, is the product of the weight of the ram (plus the equivalent of the mean effective steam pressure) and the distance through which the ram travels. A light ram may develop the same energy in dropping through a great distance as is developed by a heavy ram dropping through a short distance. However, at the end of the stroke there is a great difference in velocity. In recent years practically all manufacturers have adopted relatively heavy hammers striking at low velocities.

TABLE 8.—DATA ON PILE HAMMERS, HEAVY-DUTY TYPE

Make and type	Model	Weight, pounds: Complete unit	Weight, pounds: Ram	Strokes: Per minute	Strokes: Length, inches	Energy delivered (computed), foot-pound per blow	Power required: Steam, boiler horsepower	Power required: Comp. air, cubic feet free air per minute	Equivalent fall, feet
								At 100 lb.	
McKiernan-Terry double-acting (Also builds sgl. acting)	9B3	7,000	1,600	145	17	8.750	45	600	5.5
	10B3	10,850	3,000	105	19	13.100	50	750	4.4
	11B3	14,000	5,000	95	19	19,150	60	900	3.8
	Special		10,000			50,000			
								At 100 lb.	
Union double-acting	1½A	9,200	1,500	125	18	8,280	35	450	5.5
	1 A	10,500	1,600	120	18	10,020	40	500	6.3
	1	10,000	1,850	130	21	13.100	40	600	7.9
	0 A	17.000	5.000	90	21	22.050	60	800	4.4
	0 O	21,000	6.000	85	36	54.900	125		9.1
								At 100 lb.	
Vulcan differential-acting	3.000	7.250	3.000	133	12½	7.260	40	488	2.4
	5.000	12.140	5.000	120	15½	15.100	60	880	3 0
	8.000	18,480	8.000	111	16½	24.450	80	1245	3.0
	14.000	27.980	14.000	103	15½	36.000	100	1425	2.6
	20.000	39.050	20.000	98	15½	50.200	120	1745	2.5
								At 80 lb.	
Vulcan single-acting	2	6,700	3,000	70	29	7.260	25	580	2.4
	1	9,600	5,000	60	36	15,000	40	975	3.0
	0	16.250	7.500	50	39	24.375	60	1450	3.25
	OR	18.050	9.300	50	39	30.225	60		3 25

In the single-acting pile hammer the ram is raised by steam and then drops freely under its own weight. This type of hammer, as a rule, requires special leads to guide it and special accessory bases to adapt it to different kinds of piling. In the double-acting and differential-acting hammers the steam is applied at the top of the ram as well, and helps to drive the ram down. In the differential-acting hammer a counter-pressure is maintained to aid on the upstroke. The main advantages of the double-acting and differential-acting hammers are: the greater number of blows struck per minute, which generally cuts the driving time in half, and the ability to dispense with special leads. The fast blows result not only in faster driving and greater penetration but less damage to the piling due to practically continued vibration going through the pile, eliminating a great deal of the skin friction which quickly develops in the soil where there is a period of rest between blows.

The majority of double-acting pile hammers are fully enclosed, which is important in the prevention of accidents to operators and also in keeping foreign substance from getting into the working parts of the hammer. It is possible to employ them for subaqueous driving and allow the hammer to follow the piling down into the water, which, in some cases, has been to a distance of 80 ft. This is accomplished by admitting air at a pressure slightly in excess of the water pressure to the ram cylinder to keep out the water, and conducting the exhaust to the surface.

Most pile hammers are designed for operation by either steam or air at a pressure of 100 to 105 lb. per sq. in., and some require up to 120 lb. Table 9, developed by the authors from data secured from the manufacturers of hammers, gives in a general way the required capacities of pile hammers for different lengths and types of piling. The final selection of a hammer must, of course, take full account of all local conditions.

Rules for Pile Driving.—One of the most important rules in the driving of sheet piling is to *drive truly vertical*, keeping the hammer as vertical as possible and driving slowly and gradually. Another important point is the simple expedient, which is not practiced nearly as much on construction jobs as it ought to be, of placing a small plug on the underside of the open interlock, so that as the pile is driven down, the plug prevents earth from being driven into the exposed interlock. This helps to keep the

TABLE 9.—SELECTION OF PILE HAMMERS FOR VARIOUS TYPES OF PILING AND FOR AVERAGE AND HARD DRIVING
(Recommended size of hammer as measured by energy of blow in foot-pounds, *manufacturers recommendations;* piling weight in pounds per linear foot)

Length of pile, feet	Depth of penetration	Sheet pile*			Timber pile		Concrete pile; weight in pounds per linear foot of piling	
		Light, 20	Medium, 30	Heavy, 40	Light, 30	Heavy, 60	Light, 150	Heavy, 400
Driving through Earth, Sand, Loose Gravel. Normal Frictional Resistance								
25	½	1,000 to 1,800	1,000 to 1,800	1,800 to 2,500	3,600 to 4,200	3,600 to 7,250	7,250 to 8,750	8,750 to 15,000
	Full	1,000 to 3,600	1,800 to 3,600	1,800 to 3,600	3,600 to 7,250	3,600 to 8,750	7,250 to 8,750	13,000 to 15,000
50	½	1,800 to 3,600	1,800 to 3,600	3,600 to 4,200	3,600 to 8,750	7,250 to 8,750	8,750 to 15,000	13,000 to 25,000
	Full	3,600 to 4,200	3,600 to 4,200	3,600 to 7,500	7,250 to 8,750	7,250 to 15,000	13,000 to 15,000	15,000 to 25,000
75	½	....	3,600 to 7,500	3,600 to 8,750	....	13,000 to 15,000	....	19,000 to 36,000
	Full	....	....	5,000 to 8,750	....	15,000 to 19,000	....	19,000 to 36,000
Driving through Stiff Clay, Compacted Gravel. High Frictional Resistance								
25	½	1,800 to 2,500	1,800 to 2,500	1,800 to 4,200	7,250 to 8,750	7,250 to 8,750	7,250 to 8,750	8,750 to 15,000
	Full	1,800 to 3,600	1,800 to 3,600	1,800 to 4,200	7,250 to 8,750	7,250 to 8,750	7,250 to 15,000	13,000 to 15,000
50	½	1,800 to 4,200	3,600 to 4,200	3,600 to 8,750	7,250 to 15,000	7,250 to 15,000	13,000 to 15,000	13,000 to 25,000
	Full	....	3,600 to 8,750	7,500 to 13,000	....	13,000 to 15,000	....	19,000 to 36,000
75	½	....	3,600 to 8,750	7,500 to 13,000	....	13,000 to 15,000	....	26,000 to 36,000
	Full	....	....	10,600 to 19,000	....	15,000 to 25,000	....	26,000 to 46,000

* Energy required in driving single sheet pile. Increase these 50 per cent when driving two piles at a time.

interlock clean and facilitates driving of the next pile and is particularly useful in reducing the energy required for later extracting the piling.

In the construction of cellular steel cofferdams it is important to provide adequate guide templets to hold the empty cells in place and truly vertical during assembly and driving. Frequently such templets consist of previously driven round timber piling,

FIG. 40.—Damaged sheet piling driven too hard or deformed by boulders.

heavily braced, and provided with guide edges to which the piling may be assembled. The portable steel templet which was developed at Pickwick Landing Dam, as described in Chap. IX, has proved particularly successful in displacing the necessity of building up timber structures, the entire templet being lifted out of the completed cell and set forward for assembly of the next cell.

If the hammer is too large and drives too hard, the bottom of the piling may be readily deflected out of its straight course by a large boulder or other obstruction, and in that case the pile

may jump out of the interlock and thereby destroy the effectiveness of the sheet-pile structure. Figure 40 shows typical cases of piling which had to be uncovered after it was driven, because of the excessive leakage which developed. The severe driving is quite apparent, in one case causing the pile to curl up and in other cases to jump the interlock. The bruised condition of this piling is striking and significant, particularly when it is considered that it had to be pulled for later redriving. It is easy to understand that tremendous pulling forces must be applied to first of all straighten the piling, at least in a general way, so that it can retrace its path upward.

Pile Extractors.—The smaller sizes of McKiernan-Terry hammers may be inverted and used in driving out sheet piling. However, the heavy-duty hammers are not suitable for this purpose, and the makers offer a special type of extractor. Such an extractor is shown in Fig. 39, and the general characteristics of the standard types are given in Table 10. The Vulcan extractor is similar to the McKiernan-Terry in general characteristics, while Union employs the principle of inverting its heavy-duty hammers for this service. The specially designed pile extractor is very much lighter and shorter than an inverted hammer. Its lower weight and universal yoke at the bottom facilitate handling the extractor and laying down the pile with a minimum amount of hand labor. The extractor does not really do the extracting, but its sharp, quick blows set up vibration in the piling, breaking the skin friction and interlock friction so that the hoisting apparatus on the extractor can withdraw the loosened pile.

One size of extractor is designed to withstand approximately 100 tons of pull at its upper end. Others can withstand only a fraction of such a pull. It has occasionally been found necessary to employ heavy pulling rigs which are capable of developing between 100 and 200 tons in order to loosen the piling, particularly if it has been in the ground for a great length of time, and this requires special rigging independent of the extractor.

Some extractors are furnished with special bars for making a relatively loose connection to the piling, which is entirely inadequate where the pulling is difficult. Such bars should be designed to straddle the distortion at the top of the piling from driving and should be clamped tightly to the piling so as to develop, in

TABLE 10.—DATA ON PILE EXTRACTORS

Make	Model	Weight, Pound		Stroke		Energy of blow, foot-pound per blow	Power required			Maximum crane pull, tons
							Steam, brake horse-power	Compressed air		
		Unit complete	Ram	Per minute	Length, inches			Cubic feet free air per minute	Pressure delivery, pound per square inch	
Vulcan	200	1,500	200	550	2	250	18	312	100	25
	400	2,850	400	550	2	500	25	615	100	40
	800	5.400	800	550	2	1,000	40	1,330	100	50
McKiernan-Terry	E 2	2,600	200	450	3	700	30	400	100–125	50
	E 4	4,400	400	400	3	1,000	35	450	100–125	100
Union	5	1,625	210	190	9	910	10	100	100	
	4	2,800	370	120	12	1,390	12	150	100	
	3	4,700	700	120	14	1,780	20	300	100	
	3A	5,200	820	120	13½	2,320	25	350	100	
	2	6,600	1,025	115	16	2,375	25	400	100	
	1½A	9,200	1,500	100	18	2,500	35	450	100	
	1A	10,500	1,600	95	18	3,520	40	500	100	
	1	10,000	1,600	95	21	4,080	40	600	100	
	0	14,500	3,000	80	24	3,930	50	750	100	

addition to bearing in the hole, a very substantial amount of friction on the sides. If the bars are connected loosely to the piling the impact from the extractor will cause the holes to rip and the metal to roll upward without actually moving the pile.

Cofferdam Removal and Extracting of Piling.—As a general thing sufficient consideration is not given to the removal of

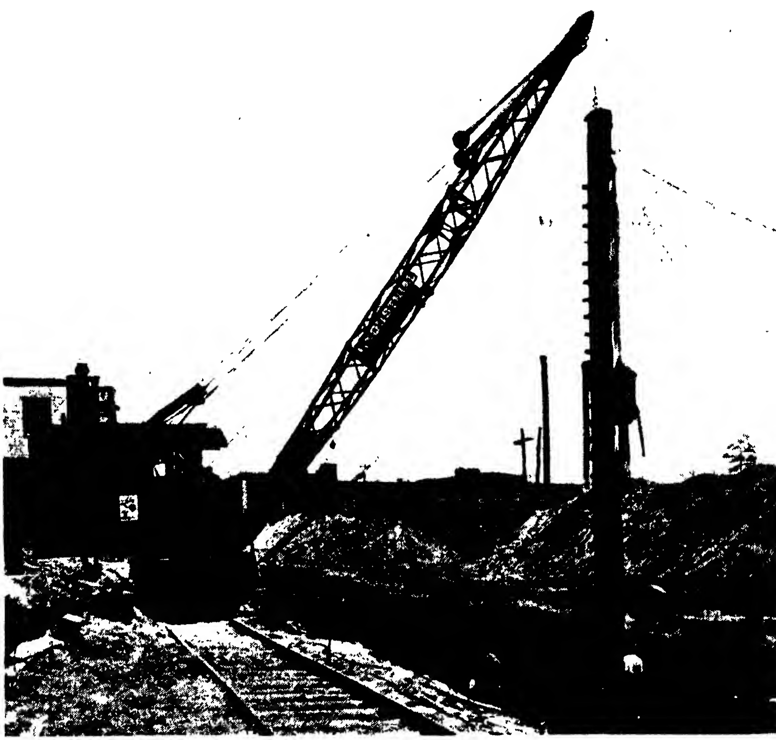


Fig. 41.—Extracting sheet piling with heavy block and tackle and mast resting on adjacent piling.

cofferdams. The dismantling of rock-filled cribs of certain designs, for example, is frequently difficult and not suited to equipment operation. The same criticism may be leveled against the extracting of sheet piling. Generally, an attempt is made to drive the piling down so as to insure a tight bottom and a minimum amount of leakage, whereas a reasonable leakage and greater pumping may be far more economical in the long run because of the saving made in extracting the piling under more

favorable conditions if it is not damaged at either the top or bottom.

Where the piling has been driven with reasonable care it is generally feasible to extract it with a pull of approximately 25 tons applied at the top of a standard extractor. Sometimes the same results may be obtained without an extractor by applying a force of 25 to 50 tons to the piling by means of a special rigging such as the one shown in Fig. 41, which consists of a

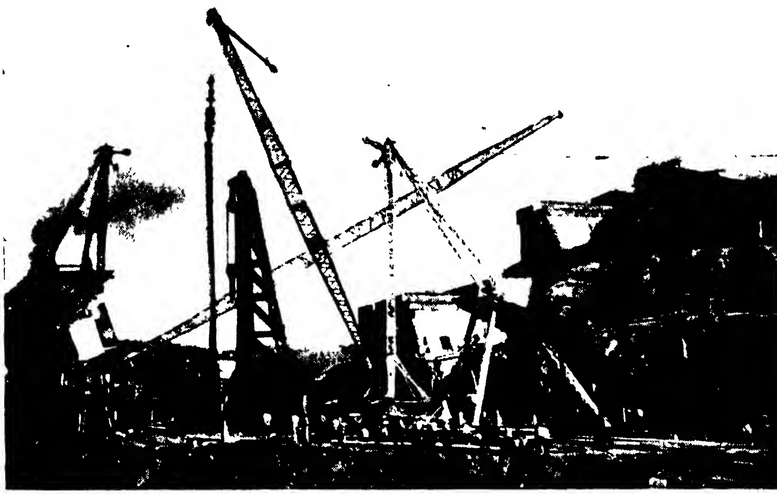


FIG. 42.—Pile-extracting rig with auxiliary A frame to develop 150 tons direct pull.

simple mast resting on the adjacent pile, and supported laterally by simple guy cables and attachment to the crane boom at the top.

Most of the extracting effort must be applied at the start in loosening the piling, especially if it has been in the ground a long time. Figure 42 shows an arrangement employed at Madden Dam, consisting of a standard skid-guy derrick operating in combination with a special A-frame mast from which was suspended a 16-part set of fall blocks. This unit was designed for a pulling effort of 150 tons. After the piling had come up 15 or 20 ft., it was sufficiently loose to permit the extractor to continue without assistance from the A frame, and the hook on the heavy-duty block was made to drop out and the extractor to continue

without stopping to disconnect the two systems. The timber A frame shown in this illustration proved particularly successful, because it permitted a great amount of deflection to occur, which gave an indication of the amount of pull being applied.

A steel unit was also employed on the same job. This was designed for a capacity of 100 tons and equipped with a special

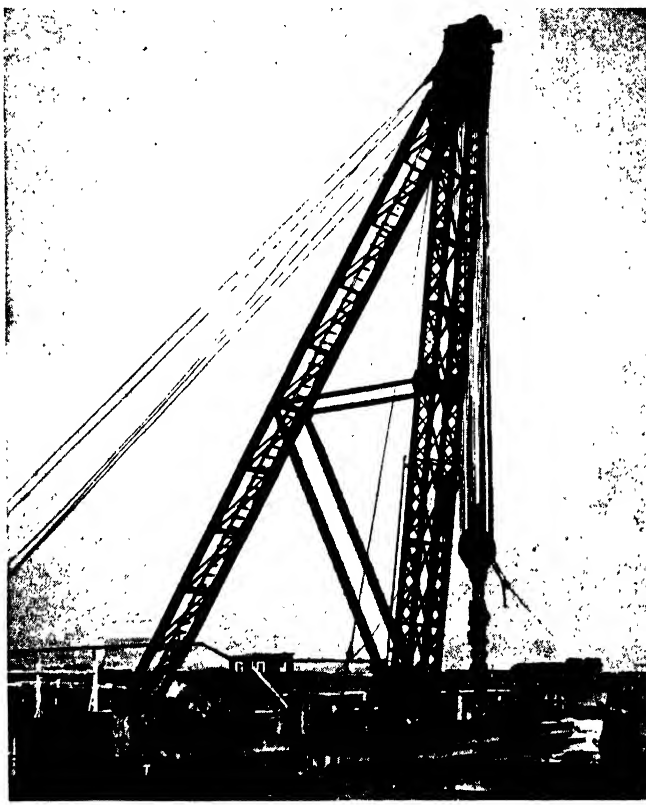


FIG. 43.—Barge-mounted heavy-duty pile extractor.

hook and a triangular yoke to which the pile and the extractor were connected. It should be noted that this triangular yoke was not very satisfactory because the main pull was applied through the block and the extractor was at one side where its impact caused a certain amount of rotation of the yoke, rather than a direct delivery of impact to the pile. This was overcome by a modified type of yoke with satisfactory results. Here the

main pull as well as the impact developed by the extractor was applied axially with respect to the piling. To accomplish this arrangement it was necessary to replace the usual type of I bars found on standard extractors with new ones which extended above the extractor to permit connection to the heavy-duty block. However, the nature of the extractor design was such as to require a pull to be applied to the top of the extractor itself, and for this purpose a second line from the derrick maintained a constant tension at this point. This arrangement proved particularly effective in extracting difficult piling. It is very important to hold the extractor directly in line with the piling for most effective pulling.

One of the most difficult extracting jobs occurred in the construction of some large piers for the City of New York, where it was necessary to remove piling varying in length from 46 to 96 ft. The pulling rig employed on this job is shown in Fig. 43. It consisted of a 70-ft. steel frame, equipped with a headpiece and fall block all containing roller-bearing sheaves and reeved with 19 parts of cable. The hoist cable was rigged to a 9- by 10-in. double-cylinder steam engine and in this manner was capable of developing a pull of 300 tons. In addition to this, a line was attached to a Vulcan pile extractor, which developed the necessary vibration to shake the piling loose. Some of the piling required a pull of 225 tons.

In the pulling of sheet piling where the interlock friction is high it is extremely important to observe the possibility of developing elongation of the interlocked edge of the pile as it is coming up, and curvature in its own plane, thus making it practically useless. The customary procedure in such cases is to step ahead a few piles and try to pull one of the sheets back in the line, where the resistance is uniform on both edges, and then step back to pull the other piling.

CHAPTER XII

PUMPING AND UNWATERING EQUIPMENT

Cofferdam Unwatering Pumps.—The common remark, "a pump's a pump," is not correct when it comes to the selection of pumps for unwatering service around cofferdams or other construction work. Some pump builders have studied cofferdam pumping and have acquired considerable experience through constant check on performance of their equipment in the field. A pump specially designed for such service may cost somewhat more than an ordinary pump, but the saving in shutdowns may readily amount to more than the first cost of the pump.

Cofferdam pumping represents a variety of problems due to the presence of foreign materials such as sand, small stones, pieces of board, shavings, etc. The ordinary pump, designed for handling clear water, has little usefulness around the cofferdam because of the small clearances between fixed and moving parts and the less convenient means to compensate for wear or to make a quick replacement of parts. Furthermore, the type of metals employed in its design is often unsuited to the demands placed upon equipment in construction service. The importance of pumping is demonstrated by such experiences as at Bonneville Dam, where the power cost alone is said to have amounted to \$50,000 over a period of 10 months.

Selection of Pumps.—A proper installation of pumps for a cofferdam depends on sound judgment as to the expected leakage or inflow, taking account, also, of the total volume within the cofferdam area where the speed of pumping out after flooding is of considerable importance. It is not easy to predict such needs, but in general it is important to provide ample capacity because when the cofferdam is ready to be unwatered there is generally much money tied up, overhead expenses are high, and any delays in getting under way are costly.

The first requirements of cofferdam pumps (Fig. 44) are ruggedness, reliability of service, and mobility. Efficiency is

important, but secondary to these points. The pump sizes most commonly employed are 10, 12, and 14 in. Sometimes it is advisable to select a combination of pumps, as, for example,

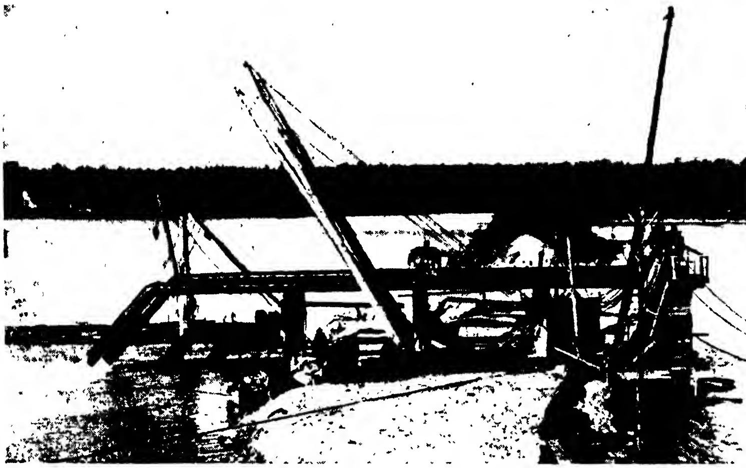


FIG. 44. Vertical-type cofferdam pumps and discharge lines with siphon outlet.

low-head pumps to remove the bulk of the water after flooding, and high-head pumps to remove the leakage.

Figure 45 shows the characteristic curves for a typical pump designed especially for cofferdam service, and the flat "hp."

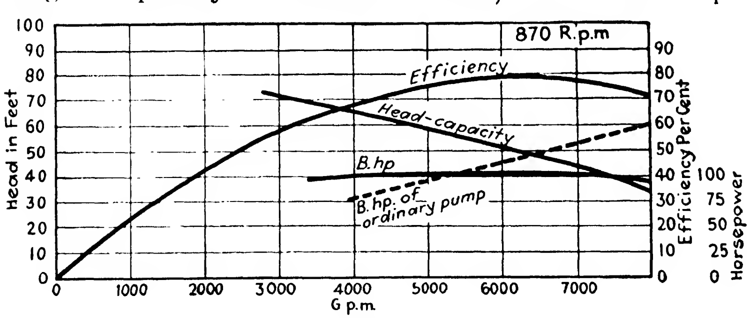


FIG. 45.—Performance curves of centrifugal pump designed for cofferdam service.

curve is of particular importance because it shows that no matter what the head is, there is no danger of overloading the motor. Certain types of pumps have a horsepower curve like the dotted line, and, under such characteristics, operating under a low head to pump out a flooded cofferdam would result in overloading the motor and burning it out, especially if it is an induction motor.

By selecting pumps designed for relatively low heads with the idea that they will operate at their maximum efficiency during unwatering service, as much as a day may be saved in pumping out a large cofferdam, and the same pumps will generally operate effectively in removing all the leakage at higher heads, after unwatering is completed, even though their efficiency is correspondingly less.

Because of the varying conditions of water level encountered in cofferdam service, the vertical type of pump is most adaptable since it can be used in places where it would be difficult to install horizontal units. Furthermore, the open-type impeller in a vertical pump prevents sand from locking the rotating parts, and priming and foot valves are eliminated. The general concentric construction allows it to be suspended on cables from timber A frames, and, when equipped with a section of rubber discharge line, it may readily be raised clear of the flood waters or lowered to any desired level.

For removing water from minor areas within a cofferdam and running it to the main sump, smaller pumps, either electric or air driven, are indispensable.

Method of Unwatering.—When first pumping out a cofferdam on earth foundations, it is particularly important to check the rate of lowering the water level and to plot the information on a chart. This will disclose any startling developments, such as a blowout along the bottom, which may occur if the pumping is too fast and the equilibrium of the earth structure is disturbed too much.

Once the cofferdam has been pumped out, it is necessary to locate a permanent pump setting where a sump may be excavated down several feet so that all the seepage water will run to this sump, and the suction ends of the pumps can be submerged a sufficient depth to provide satisfactory pumping conditions. In this connection, an interesting experience occurred at Madden Dam where the rock was overlaid with a very porous stratum of gravel, and large quantities of sand and small gravel were carried to the pumps. To simplify the pumping problem, a steel sheet-pile cell was first driven to rock within the main cofferdam area, excavated on the inside, and properly braced, after which the excavation was carried about 10 ft. down into rock to provide a permanent sump. The pumps were placed in this sump, and

this resulted in a general lowering of the water table down to the rock level and greatly simplified control of the sand and small gravel.

Installation of Pumps.—The arrangement of the discharge line deserves considerable study where the cost of power is a substantial item. Important economies can be obtained by increasing the pump capacity from 15 to 20 per cent by means of a siphon extending over the cofferdam down to the outer water level so as to reduce the net effective head on the pump (see Fig. 44). Contrary to usual conceptions, pump experts have found that the siphon will not break so long as the velocity in the discharge line in feet per second is greater than $5.5\sqrt{D}$, where D is the diameter of discharge pipe in feet.

On most modern jobs electric-driven pumps are used, but, in view of the great importance attached to maintaining a dry cofferdam at all times, it is highly desirable to have either a gasoline-driven pump or generator set to supplement the main power supply in case of failure, which usually occurs during stormy weather when reliable unwatering service is most urgently needed. An important safety requirement to keep in mind for electric pumps is the use of low-voltage motors and starting equipment, say 220 or 440 volts, because of the frequent servicing, shifting up or down, and general work required around them in wet weather.

Wellpoints.—Figure 46 shows typical features of a wellpoint system. Wellpoints have come into very common service, on construction jobs with porous foundations, for lowering the ground water below the working level so that all operations can be carried on in the dry. The wellpoints are generally 20 ft. long and equipped with nozzles, making it possible to apply pressure at the top to jet them down into the ground. The entire series of points is connected to a header line to the pump. The amount of water obtainable per wellpoint depends largely on conditions of the water-bearing stratum. In saturated sand sufficiently coarse to prevent movement and clogging of the screens on the wellpoint, it is claimed that 35 to 40 gal. per min. can be pumped per wellpoint, although this probably is the maximum. In fine sand the flow is considerably less; 28 gal. per min. is probably a high average.

The following information was obtained from an experiment conducted at Pickwick Landing Dam for measuring the movement of ground water. Within a steel-sheet-pile test cell, partly excavated on the inside, 47 wellpoints were assembled below normal ground level in a water-bearing stratum of gravel and connected through an 8-in. header to a pump of 2,000 gal.

FIG. 46.—Wellpoint installation and collecting header. Pump located in enclosure.

per min. capacity. After each test a number of the wellpoints were shut off by means of special plug valves and the test was repeated. The following results were obtained:

Number of Wellpoints	Total Discharge, Gallons per Minute
47	290
36	290
30	284
22	258

This indicated that only half the wellpoints were necessary for the particular area to pump practically as much water as was brought forth in the full installation. Under the final conditions each wellpoint delivered approximately 10 gal. per min.

The average pump size for wellpoint service is approximately 1,300 gal. per min.

Clear-water Pumping.—The water requirements for a large job have already been listed for a typical case in Table 3. The selection of pumps for clear-water supply is usually a simple matter unless the head is very high. The accompanying Table 11 gives representative characteristics of pumps for most of the ordinary requirements.

TABLE 11.—DATA FOR SELECTION OF CENTRIFUGAL PUMPS
(Single stage—sizes 5-, 6- 8-, 10- and 12-in. discharge)
(Second figure is horsepower of 60-cycle motor)
A = 3,450 R.p.m.
B = 1,750 R.p.m.
C = 1,150 R.p.m.
D = 860 R.p.m.
(Bryon Jackson Data)

Gal. per minute	Head, feet								
	40	60	80	100	120	160	200	240	300
500	5″ 10*C*	4″ 10*B*	4″ 15*B*	4″ 20*B*	4″ 20*A*	4″ 30*A*	4″ 40*A*	3″ 50*A*	3″ 60*A*
600	5″ 10*C*	5″ 15*C*	5″ 20*C*	4″ 25*B*	4″ 25*A*	4″ 35*B*	4″ 50*B*	3″ 50*A*	3″ 75*A*
700	5″ 10*C*	5″ 15*C*	5″ 20*C*	5″ 25*B*	4″ 30*B*	4″ 40*B*	4″ 50*B*	4″ 60*A*	4″ 75*A*
800	5″ 10*C*	5″ 20*C*	5″ 20*C*	5″ 25*A*	5″ 35*B*	5″ 50*B*	4″ 50*A*	4″ 60*A*	4″ 75*A*
900	6″ 10*B*	6″ 15*B*	6″ 20*B*	5″ 30*B*	5″ 35*B*	5″ 50*B*	5″ 75*B*	4″ 75*A*	4″ 100*A*
1,000	6″ 15*B*	6″ 20*B*	6″ 25*B*	5″ 30*B*	5″ 40*B*	5″ 60*B*	5″ 75*B*	4″ 75*A*	4″ 100*A*
1,200	6″ 15*B*	6″ 20*B*	6″ 30*C*	6″ 40*C*	6″ 50*C*	5″ 60*B*	5″ 75*B*	6″ 125*B*	6″ 150*B*
1 600	8″ 20*C*	8″ 30*C*	8″ 40*C*	6″ 50*C*	6″ 60*C*	6″ 100*B*	6″ 100*B*	6″ 125*B*	6″ 200*B*
2,000	8″ 25*C*	10″ 35*C*	10″ 50*C*	8″ 60*C*	8″ 75*C*	8″ 100*C*	6″ 125*B*	6″ 150*B*	6″ 200*B*
2,500	8″ 30*C*	10″ 50*C*	10″ 60*C*	10″ 75*C*	8″ 100*C*	8″ 125*C*	6″ 150*B*	6″ 200*V*	8″ 250*B*
3,000	10″ 40*C*	12″ 60*C*	10″ 75*C*	10″ 100*C*	10″ 100*C*	10″ 150*C*	8″ 200*B*	8″ 200*B*	8″ 250*B*
3,500	12″ 50*C*	12″ 75*C*	12″ 100*C*	10″ 100*C*	10″ 125*C*	10″ 200*C*	10″ 250*B*	8″ 250*B*	8″ 300*B*
4,000	12″ 50*C*	12″ 75*C*	12″ 100*C*	10″ 125*C*	10″ 150*C*	12″ 200*C*	12″ 300*C*	10″ 300*B*	8″ 350*B*
4,500	12″ 60*D*	12″ 100*C*	12″ 125*C*	12″ 150*C*	12″ 200*C*	12″ 250*C*	12″ 300*C*	10″ 350*C*	10″ 450*B*
5,000	12″ 60*D*	12″ 100*C*	12″ 125*C*	12″ 150*B*	12″ 200*B*	12″ 250*C*	12″ 300*C*	12″ 400*B*	10″ 450*B*

CHAPTER XIII

EXCAVATING EQUIPMENT

A group of foremen and the field engineer were discussing a mean little problem of excavating. A variety of equipment was available for the job, including a dragline, two power shovels, and a cableway. The group was concentrating studiously on how to do the job when the contractor himself walked in and, noting the trend of the conversation, remarked: "Now, boys, before you decide what machine to use, you've got to decide where you are going to put the dirt and how you are going to get it there. Are you going to dump it in the spoil bank? Are you going to use it for backfill? Are you going to haul it up to the ridge for the earth dam? Or are you going to take it up to the commissary and sell it for grapenuts?"

This trite remark had the desired effect of pointing out that the term "excavation" in its general use on construction work does not mean "to dig a hole," but "to remove earth or rock *here* and place it *there*." In other words, means of transporting must be considered in making the best selection of digging methods.

The material may be utilized for building other parts of the work, roads, backfills behind completed structures, developing areas for switchyards or other permanent uses, delivering the rock to the aggregate plant where it is crushed and processed for concrete, or developing an area and a site for the service plant during construction, such as shops and warehouses. At other times excavated material may have to be put into temporary storage, from which it may be later reclaimed for some useful purpose, or it may be dumped directly into a spoil bank.

General Considerations.—Among the considerations which enter into the planning of excavation are the total yardage and working time available; the type of excavation and nature of the area, as, for example, quarry, ditch, canal, open, confined, or subaqueous; and the designed rate of output for the entire plant.

One of the most important principles to keep in mind in designing a balanced plant is to take account of the swell of material when it is converted from a solid to a loose state for transportation.

Elements which enter into a proper layout of the work include such questions as where to open up the excavation, which direction to travel, location of ramps, depth of cuts, width of cuts, where to spot equipment to maintain steady production. At all times it is important to keep a balanced running of excavating and hauling equipment and to take fullest account of the natural advantage of the pit layout.

The actual process of equipment selection requires a consideration of the foregoing elements and their relationship to type of equipment, such as fixed, movable, land, or floating equipment; also the type of power available, such as electric, gasoline, Diesel, or steam. Further obvious elements are the questions of ruggedness, ease of replacement of parts, and their availability from manufacturers or local agents. The problem of equipment selection for excavation is such an involved task that no detailed rules can be set down. Excavating equipment seldom operates at maximum efficiency, as is evidenced when one considers the vast number of variables which affect the output of such equipment. A representative list of such variables is included in Table 12.

A brief description of the various types of modern excavating equipment follows:

Front- and Side-casting Bulldozers.—Bulldozers attached to heavy-duty tractors are rapidly being employed as primary excavators and movers instead of serving merely as spreaders or levelers or as devices for base stripping. They are a remarkably versatile tool and almost indispensable on most excavating jobs. According to the U. S. Bureau of Public Roads, a 4- by 10-ft. blade loads in a distance of 30 ft. when traveling 125 ft. per min. and carries from 2 to 3 yd. per load. The easiest and most effective work is done in moving earth downhill on short hauls, the limit in grade being such as to permit the machine to reverse and return uphill (see Fig. 47). Spillage beyond the ends of the bulldozer is prevented by traveling in the same path with built-up sides of earth; the amount of material which can be moved is thereby increased 10 per cent. A similar effect is obtained by operating two bulldozers side by side. This equip-

TABLE 12.—VARIABLES WHICH AFFECT OUTPUT OF EXCAVATING EQUIPMENT

Type of excavator	Classification of variables, output controlled by			
	Physical conditions of job	Materials to be handled	Limitations in machine	Method of operation
Draglines, shovels, tower excavators, bulldozers	1. Size of excavation area 2. Type of bottom: *a.* Muddy, *b.* Hard, *c.* Smooth, *d.* Rough, *e.* Sandy, *f.* Rocky 3. Distance between loading and dumping 4. Required lift—digging to dumping 5. Depth of excavation 6. Proximity to supply of fuel and parts 7. Weather 8. Obstruction and interference from other structures 9. Time available 10. Power available 11. Altitude (effect on engines)	1. Type of material: *a.* Sand, *b.* Gravel, *c.* Rock, *d.* Clay 2. Size of pieces 3. Moisture content 4. Foreign matter 5. Weight of material as loaded	1. Size of dipper, bucket, or load 2. Angle of swing required 3. Necessary reach—loading to dumping 4. Height of dump 5. Maneuverability of machine under various bottom conditions 6. Speed of machine performance 7. Quality of machine and maintenance 8. Quality of fuel and reliability of supply	1. Number of units in operation 2. Method of transporting excavated materials 3. Skill and experience of operators and of supervisors 4. Layout of cuts, ramps, and roads 5. Deposition of material (loading or spot dumping) 6. Size of receiving units
Dredges	1. Distance to discharge point 2. Presence of trees, roots, vegetation, obstructions, etc. 3. Route to discharge point—by water or land 4. Required lift, suction, and discharge 5. Anchorage available 6. Proximity to supply of fuel and parts	1. Type of material 2. Size of pieces 3. Abrasiveness of material 4. Foreign matter	1. Size of suction, pump, and discharge lines 2. Length of discharge line 3. Suction vacuum on pump 4. Discharge pressure 5. Action of cutterhead 6. Quality of machine and maintenance 7. Quality of fuel and reliability of supply 8. Alignment of pipe line	1. Depth of cut 2. Type of power used 3. Method of carrying discharge pipe 4. Deposition of material (fill or waste) 5. Skill and experience of operators and supervisors 6. Layout of cut 7. Location of booster pumps 8. Method of feeding dredge (underwater digging or sluice feed)

ment is not well suited for moving material uphill because the load tends to spill around the ends of the blade.

In moving loose materials over relatively short distances this equipment is capable of doing the job at from 4 to 7 cts. per cu. yd.

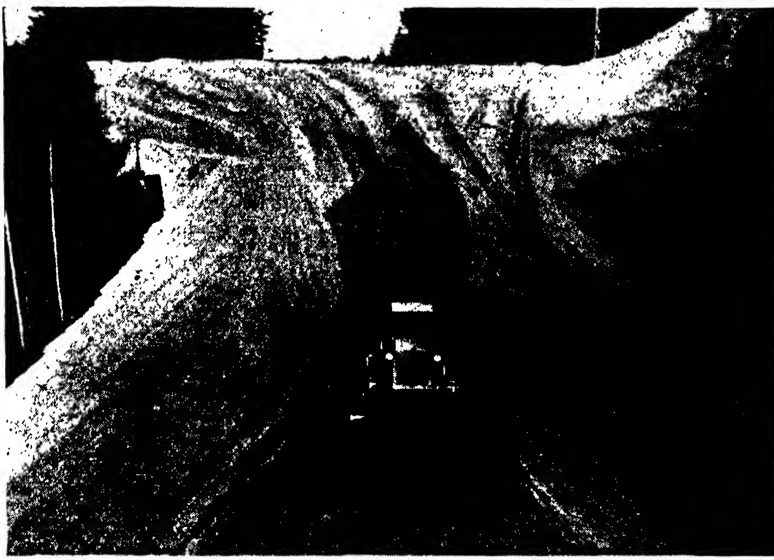


FIG. 47.—Bulldozer making highway cut and fill of 300,000 cu. yd. across deep canyon

Bulldozers are also very important tools in an excavation plant for keeping the job shaped up at the digging and dumping end and to facilitate rapid movement of the hauling equipment.

TABLE 13.—BULLDOZER CAPACITY IN SAND OR LOOSE SOIL
(Cubic yard per hour, compact measure, moved by bulldozer and 50-hp. tractor)

Length of haul, feet	10 per cent uphill grade	Level	Downhill grade	
			10 per cent	20 per cent
50	50	80	150	200
100	30	50	90	130
200	15	26	50	70
300	10	17	30	45
400	7	12	23	33

Side-casting bulldozers have their blade set at an angle and can gouge out the earth and push it over the hillside. They are used in hilly country for opening up jobs where 10-ft. trails can serve as access roads for bringing in heavier equipment.

Table 13 gives some indication of the capacity of the bulldozer as an earth-moving tool.

Scrapers.—Scrapers, as a further example of combination excavators and movers, are mostly adaptable to plowable materials; they are not suited to hard rock. In certain kinds of sand the material will not pile up into the scraper, while wet or muddy materials make discharging of the scraper difficult. From small, animal-drawn scrapers the development in recent years has been rapid to the present tractor-drawn 12-yd. size, and in some instances larger sizes. These large-capacity scrapers have rapidly gained acceptance, particularly since they serve as an ideal transporting device, while at the same time eliminating the need for loading equipment. They are specially suited to short hauls of 500 to 1,000 ft. and in some cases up to about 3,000 ft. In general, the loading distance for a scraper is about 100 ft. at a speed of 120 ft. a minute. With loose materials it is necessary to expect heavy spillage when loading on a downhill grade. A scraper leaves the pits as well as the dump areas in level shape and thus assists in its own freedom of movement. Since scrapers are essentially a hauling unit, their performance is discussed in greater detail in Chap. XIV on hauling equipment.

Under average conditions of a 600-ft. haul, the loading and hauling of earth can be done for 5 to 7 cts. per cu. yd.

At present there are many makes and sizes of scrapers, and no standards have as yet been developed. Some units drag along on their bottom and carry part of the load ahead at slow speed; some have gates in front to reduce spillage; others tilt back during travel. Practically all makes are powered by cables or hydraulic pressure from a power take-off on the tractor.

Rooters.—An important auxiliary tool for scrapers is the heavy-duty rooter which is drawn by a tractor and can plow up stiff clay and the softer rock formations, which would otherwise require shooting and loading by shovels.

Elevating Graders.—The elevating grader (Fig. 48) consists essentially of a tractor-drawn steel frame, which has a plowing blade to cut the earth and deflect it on to a short section of belt

conveyor. As in the case of scrapers, it is suited only to plowable material. Elevating graders are used for a variety of purposes, as, for example, at Pickwick Landing Dam, where a large circular pit was developed which eventually formed the excavated area for the powerhouse site, and the material was loaded and hauled to a rolled-fill earth dam. At Fort Peck Dam the entire base of the dam was stripped with elevating graders and the earth loaded into trucks and hauled away. A total of 4,100,000

Fig. 48.—Elevating grader for loading wagons.

yd. was moved in 120 days, using 9 tractor-drawn graders and 250 trucks. On the best day 55,000 yd. was moved in 14 hr. This system is in marked contrast to older methods such as railroad cars and shovels which, as a matter of interest, were considered for this particular job.

In recent years substantial improvements have been made, and the modern units are capable of loading 300 to 400 yd. per hour at from 2 to 4 cts. per cu. yd. under good conditions.

In the selection of graders the factors which require consideration and govern their output are the nature of the soil, its consistency, and its freedom from stumps and roots; power and speed of the tractor; dimensions of pit and surface conditions; the amount of time lost in turning; the amount and number of hauling units, their capacity, whether large or small, and the clearance under the conveyor arm to permit rapid transfer of hauling units.

It is important that hauling units be fast and easily maneuvered in order to make the change under the grader as rapidly as possible to maintain a high output. For the larger jobs it is advisable to use elevating graders with a power unit mounted directly on the grader. On lighter jobs it is customary to operate the belt on the grader by means of a power take-off from the tractor which pulls the grader. Table 14 gives some indication of the excavating capacity of typical graders. The modern tractor and scraper outfit has become so adaptable to a great variety of earth-moving requirements that the elevating grader is finding application only in special circumstances and is not so popular as it was at one time.

TABLE 14.—OUTPUT OF ELEVATING GRADERS LOADING WAGONS
(Cubic yards per hour compact measurement)

Grader width of belt, inches	Belt power	Tractor	Loading conditions		
			Excel-lent	Fair	Poor
42	Power take-off	Diesel, 50 hp.	215	155	95
42	Engine-mounted	Diesel, 50 hp.	275	200	125
48	Power take-off	Diesel, 75 hp.	325	240	150
48	Engine-mounted	Diesel, 75 hp.	370	270	170

Power Shovels.—Power shovels are best suited to close-range work (Fig. 49). They have good control of digging and are speedy and there is little lost motion. Most makes up to 2-yd. capacity can make two to three cycles per minute. Determination of proper size depends entirely upon job conditions, but in any case it is important to select a size of dipper to suit the capacity of hauling units so as to permit the use of full dipper loads up to the point of spilling over the edges on the last dipperful. It is important not to overtool for maximum output, because this means greater expense when the shovel is shut down. It is well to keep in mind the large number of variables that affect the output of excavating equipment, as has already been mentioned.

There is practically no standardization in the field of shovels, and it is surprising what a high-pressure seller can do in meeting competitive conditions and offering equipment which the unwary

contractor does not fully recognize until he has been using it for a while. Such details as short or long dipper sticks, ball or roller bearings or plain bronze bearings, the use of ordinary metals where special alloys would add greatly to the life, or open gears in the place of cut gears fully enclosed and running in oil, all have a decided effect on performance but may be unobserved details which can be varied to suit the price. Some machines are designed to operate satisfactorily with narrow dragline buckets, whereas a wide bucket is more satisfactory, loads

Fig. 49.—Electric powered shovel with 2½-yd. dipper loading rock.

quicker, but requires more power. Maneuverability varies with different makes.

Similar elements go into the selection of engines. Is the horsepower of the engine rated bare or with full auxiliaries, and what are the maximum speed and torque of the machine? A high horsepower at high speed is of less practical value in shovel design, but is frequently offered because such equipment is cheaper. The bigger horsepower sounds important, and this all helps to make a sale.

One of the chief advantages of the modern shovel is its convertibility into dragline, clamshell, crane, scoop, or ditcher, although it should be remembered that some shovels are not so well equipped for conversion as others. Only one or two shovels are equipped for conversion to crane service with a so-called live

boom, or a fast-action boom, which is particularly useful in setting steel. Most shovels have worm-gear drives for booming control, which is a slow operation, but a live-boom machine is actuated by spur gearing, which is considerably faster. When it comes to changing speed for various conditions, some require-

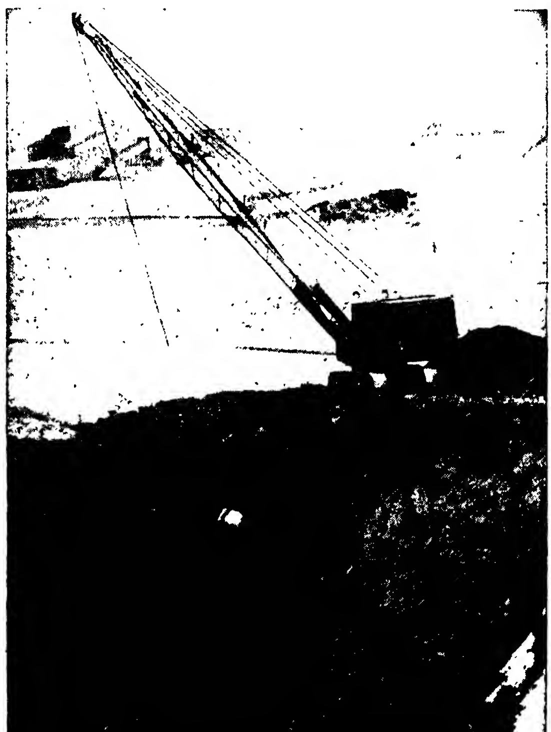


FIG. 50.—Shovel converted into dragline for deep excavation.

ments can be met by changing the cable reeving or the lagging on the drums, but here again only one or two machines are equipped with two speeds and with speed-changing levers for all operations, which is a great advantage under certain operating conditions.

The extra expense of first-class operating control systems will usually pay for itself many times over. Many of the large excavating units which represent a high investment and therefore

demand maximum efficiency of operation, obtain such efficiency by relieving the operator of as much of the "human element" control as possible through the use of special electric equipment, known as the Ward Leonard control system. Such a system consists essentially of a d.c. motor-generator set mounted on the shovel and driving separate motors connected to each machine

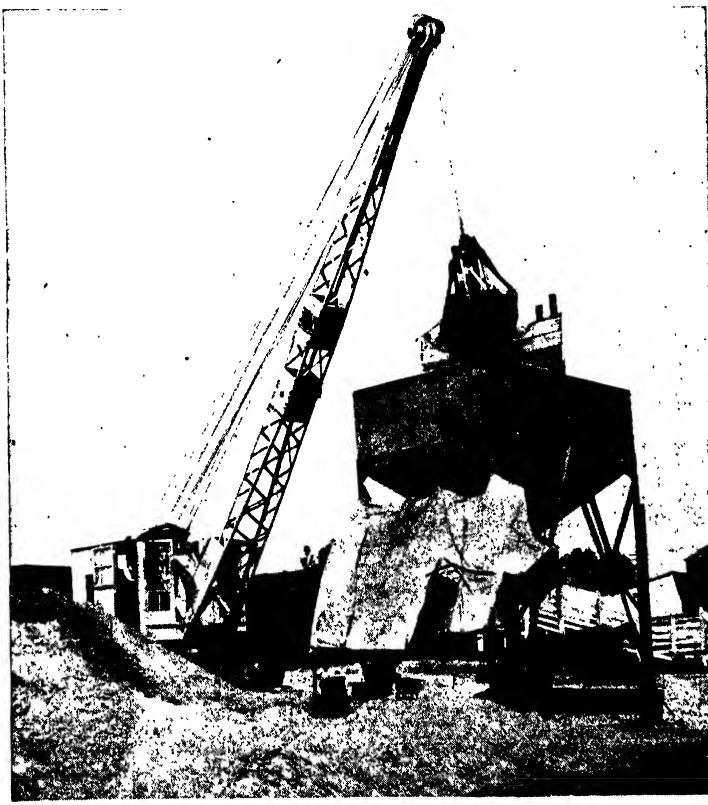


FIG. 51.—Shovel converted into clamshell crane for high loading.

function, such as hoisting, swinging or crowding. This permits effective control of the equipment through manipulation of the electrical characteristics and by means of automatic relay equipment all operations are performed under maximum permissible speed and accelerations without overstressing any part of the machine on the one hand, and without sacrificing speed or efficiency on the other.

Draglines.—The dragline (Fig. 50) is one of the most flexible excavating tools. It has more reach than a shovel, both for excavating as well as for disposal, can dig far below its base, as well as at almost any other location, can reach under water, is not seriously retarded by weather, and permits a great deal of freedom in spotting the hauling equipment for loading. However, it cannot handle hard digging so efficiently as a shovel. The boom is generally set at a fixed angle of 30 to 37 deg.

Fig. 52.—Shovel converted into trench hoe.

The greatest possibility for mistakes in planning a dragline job lies in the selection of the bucket. For each kind of earth or rock there is one type of bucket which will perform most effectively. It's just like selecting the proper cutting tool for trimming down a piece of metal in a lathe. The combination of width of bucket, balance of bucket, height of bucket, number and angle of teeth and location of teeth with respect to the dragline yoke, and the relationship between length of boom and over-all capacity of bucket all affect the output of a machine in different materials. One successful dragline contractor considers these matters important enough to design his own buckets and pay several times the price of standard buckets, because the extra cost is quickly recovered by the increased output of the machine. Practical dragline performance is too frequently considered satisfactory if the output is 50 per cent of its theoretical ability, largely because the importance of such details is overlooked.

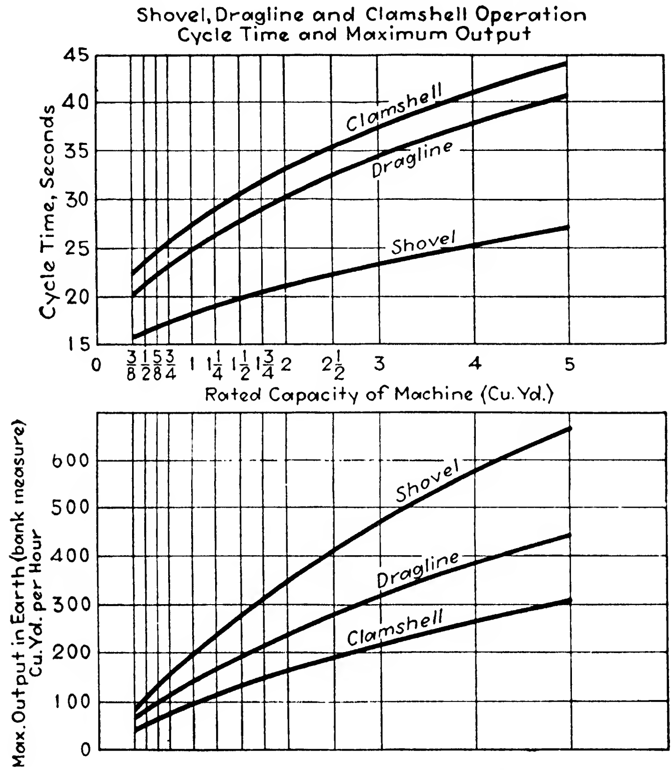
Sometimes easy digging warrants the use of oversize buckets, such as the excavation of sand on the Florida Canal, where a number of 1¾-yd. machines were equipped with 2½-yd. buckets on 50-ft. booms. This usually necessitates a higher boom angle

TABLE 15.—CAPACITIES AND DIMENSIONS OF CONVERTIBLE CRAWLER EXCAVATING MACHINES

Rated capacity, cubic yard	Power, horsepower	Speed of travel, miles per hour	Shovel: Cycle time required for 90-degree swing, second	Shovel: Weight, pound, Complete unit, Operating	Shovel: Cost*, Complete unit	Shovel: Length, feet, Boom	Shovel: Length, feet, Dipper handle	Shovel: Boom angle 45 degrees, Maximum dump height, feet	Shovel: Boom angle 45 degrees, Radius at maximum dump height, feet	Shovel: Boom angle 45 degrees, Maximum digging radius, feet	Dragline and clamshell (allowable load—66 per cent of tipping): Rated capacity, cubic yard	Dragline and clamshell: Length of boom, feet	Dragline: Angle of boom, degrees	Dragline: Maximum radius full bucket, feet	Dragline: Load rating bucket and load, pound	Dragline: Maximum dump height, feet	Clamshell: Maximum dump height, feet	Clamshell: Radius at maximum dump height, feet	Clamshell: Maximum digging radius full bucket, feet	Crane 75 per cent of tipping: Length of boom, feet	Crane: Maximum load at radius, Pound	Crane: Maximum load at radius, Feet	Crane: Maximum clear height, feet
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
3/8	35	1 to 4½	15	16,000	$6,000	13	11	12	16	20	3/8	28	42	23	1,825	14	21	15	19	28	7,000	10	27
½	54	1.5 to 0.85	16	28,000	7,000	16	13	14	19	23	½	35	33	32	2,800	15	26	20	30	35	12,000	12	34
5/8	60	0.85	17	32,000	7,500	16	13	14	19	23	5/8	35	35	32	3,300	15	23	18	30	35	13,000	12	34
¾	76	0.85	17	50,000	10,600	18	14	15	21	26	¾	35	35	32	5,000	15	24	21	35	35	21,000	12	34
1	105	0.85	18	70,000	13,200	19	15	16	25	29	1	40	30	40	6,000	15	28	24	36	40	32,000	12	39
1¼	115	0.75	19	80,000	14,500	20	16	16	26	31	1¼	45	30	40	6,800	16	32	27	35	45	39,000	12	45
1½	132	0.75	20	95,000	16,800	21	16	16	26	31	1½	45	34	42	7,700	18	32	27	37	45	49,000	12	45
1¾	148	0.75	20	110,000	19,600	22	17	17	27	33	1¾	50	36	45	9,000	23	36	30	43	50	61,000	12	47
2	170	0.875 to 1.625	21	135,000	25,000	23	18	19	29	33	2	50	38	45	11,000	23	36	30	45	50	77,000	12	55
2½	215	0.55 to 0.92	22	160,000	39,000	27	18	20	30	35	2½	60	28	60	13,000	20	45	35	60	60	95,000	15	65
Ward Leonard Quarry Machines																							
2¼	...	0.75		170,000	35,500	30	18	18	31	36	3 Light	65	35	60	14,000	29							
2½	...	0.875		226,000	48,000	30	19	22	35	40	3 Heavy	60	35	65	16,900	27							
3	...	0.75		274,000	59,000	32	22	22	38	43	3½ Heavy	70	34	65	19,850	27							
4	...	0.91		340,000	70,000	32	22	21	39	45	4½ Heavy	80	35	72	25,500	30							

* Estimated.

and resulting decrease in operating range. However, where such an arrangement exceeds the permissible line pull or total weight



Classes of Material	Coefficient		
	Shovel	Dragline	Clamshell
Light, moist clay or loam which heaps up on bucket or dipper	1.00-1.15	1.00-1.15	1.00
Ordinary earth or loose sand & gravel	0.80-0.90	0.80-0.90	0.80
Light clay mixed with gravel	0.65-0.75	0.65-0.75	0.50
Heavy clay and boulders	0.50-0.65	0.45-0.65	0.40
Blasted rock, hardpan or tough rubbery clay	0.35-0.45	0.30-0.40	0.20

FIG. 53.—Cycle time and output curves for various sizes of shovels, draglines, and clamshells.

Note: This chart indicates the maximum output for favorable conditions, assuming no lost operating time and a 90-deg. swing to dump. The practical output may be 85 to 50 per cent of indicated output depending on skill and experience of operator and local conditions.

Modify output given on chart by coefficients for different classes of material tabulated above.

of the loaded bucket for which the machinery was designed, the greater number of repairs and shutdowns may minimize any advantages.

The capacities of shovel dippers and dragline buckets are commonly stated in terms of level-full measure in cubic content. Thus, a shovel handling earth must be heaped if a load of equivalent bank measure is handled. In handling damp earth the load in terms of bank measure may be about 10 per cent greater than rated bucket capacity. In handling rock the load may be 30 to 50 per cent less than solid measure, depending upon the voids in the rock.

Clamshell, Ditcher, or Scoop.—The adaptations of a convertible shovel for clamshell (Fig. 51), ditcher (Fig. 52), or scoop work are largely special and only rarely are they used as production units on an excavating job. The clamshell is particularly suited to cleaning out holes, reclaiming gravel and loading into bins. The scoop is essentially a cleanup tool from hard or level surfaces, while the ditcher largely supplements the continuous bucket ditcher where the material is too hard for the latter, or contains roots, stones or other foreign matter which requires more power for removal.

Table 15 gives the principal dimensions for standard convertible shovels, and Fig. 53 is a chart of average output and cycle time for shovels, draglines, and clamshells of various sizes.

Walking Dragline.—The walking dragline, Fig. 54, as an excavating machine, is more or less in a class by itself. Its principal features include unusual simplicity of the traveling mechanism, simple structural design, large sizes, up to 12- to 14-yd. buckets on 175-ft. boom, and easy mobility (see Table 16). The machine can travel on soft bottom, its bearing pressure being only 4 to 6 lb. per sq. in.

No steering mechanism is required as the machine always travels opposite to where the boom points, and changes in direction are quickly accomplished by swinging the revolving body. The machine is designed to be quite free from wet-weather interruptions and has an exceptionally fast hoist and swing. High efficiency of operation is obtained, the time cycle for all sizes being less than 1 min. As a rule, Diesel engines are employed, with remote-control operating levers, either electric or air powered.

Quite a number of these machines have been equipped with aluminum booms, which raise the cost of a machine about 5 per cent over one with a steel boom, but the weight reduction

TABLE 16.—WALKING DRAGLINES

Model number	Bucket size, cubic yard (see note below)	Boom length standard, feet	Diesel power unit: Speed, revolutions per minute	Diesel power unit: Power, horsepower	Working weight, tons	Factory price	Operating dimensions, feet (boom angle, 25 degrees): Digging: Reach	Digging: Depth standard ropes	Dump: Height	Speeds: Travel miles per hour	Speeds: Hoist, feet per minute	Average cycle time 110-degree swing, seconds: Earth	Gravel	Well-blasted rock	Output at 100% plant efficiency, cubic yard per hour: Earth†	Gravel†	Well-blasted rock‡
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1-W	1½ H	35	650	80	35	$17,000	38	18	8	0.28	132 to 112	30	33	39	162	147	82
	1 H	40					42	20	9						108	98	55
	¾ H	45					52	25	13						81	74	41
2-W	2 H*	60	360	110	73	31,500	62	32	15	0.23	151 to 129	36	40	47	180	162	92
	1½ H	70					72	38	22						135	121	69
3-W	3½ H	60	300	140	122	48,500	65	29	14	0.19	154 to 139	45	50	59	252	230	128
	3 H*	70					74	25	20						216	196	110
	2½ H	80					83	21	24						180	164	92
4-W	5 H	80	300	210	233	80,000	85	43	20	0.22	159 to 134	50	55	65	324	294	166
	4 H	100					103	49	31						259	236	133
	3 H	120					121	38	41						194	176	100
5-W	6 W	80	360	250	150	68,500	82	46	20	0.18	160 to 140	43	47	56	450	414	232
	5 W*	90					91	52	26						376	345	193
	4½ W	100					100	58	29						340	310	174
6-W	6 H*	100	300	280	305	103,000	104	58	26	0.19	168 to 155	55	60	72	354	324	180
	5 H	115					118	52	33						294	270	150
	5 H	125					127	48	37						294	270	150
6160	7 H	140	360	420	445	135,000	143	80	43	0.18	158 to 150	60	66	78	378	344	194
	6 H*	160					161	72	51						324	294	166
	5 H	175					175	64	59						270	245	139
10-W	11 H	140	260	450	700	210,000	144	81	40	0.17	163 to 154	60	66	78	594	540	305
	10 H*	160					162	92	49						540	490	278
	8 H	175					175	94	56						432	392	222

H, heavy duty; *W*, medium duty
* Standard sizes.
† Bucket efficiency 90 per cent.
‡ Bucket efficiency 60 per cent.

makes possible increases of 15 per cent in boom length, or 20 per cent in bucket capacity.

These machines have been particularly popular in the construction of levees and canals where their exceptionally long reach frequently permits digging and disposal in one operation, or in some cases the material might be rehandled once or twice, thus eliminating the need for transporting equipment.

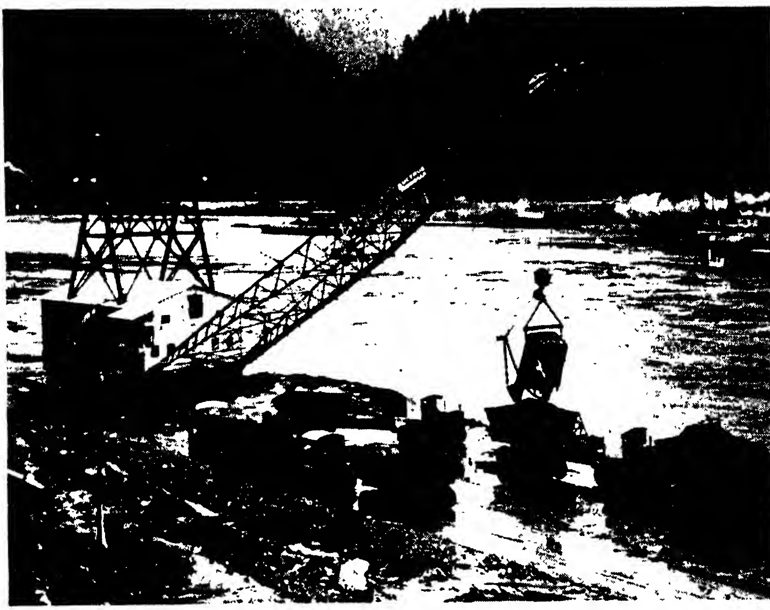


FIG. 54.—Long-boom walking dragline excavating from river bottom and loading into extra-large hauling units.

Typical performance records include a 5-W machine with oversize 8-yd. buckets and 80-ft. boom on the Florida Canal, averaging 8,000 to 10,000 yd. per day, with a maximum of 14,690 yd. This machine produced 260,000 yd. maximum per month and operated at an average yardage of 360 yd. per hr.

On the All-American Canal in California four 10-W machines with 12-yd. buckets and 165- to 175-ft. booms, operated by Diesel engines, worked at a contract price of 8 to 12¼ cts. per cu. yd.

Slack-line Cableway Excavators.—The slack-line cableway excavator is essentially a tool which digs, conveys, and elevates

by means of a bucket running on a cable, the entire operation under the control of one man. This class of equipment is subdivided into two types, one known as cableway excavators and the other as cableway drag scrapers. This equipment is particularly suitable where the excavated material is to be hauled any distance from 150 to 1,000 or 1,500 ft. and elevated to a bank or a higher dumping point adjacent to the excavation area.

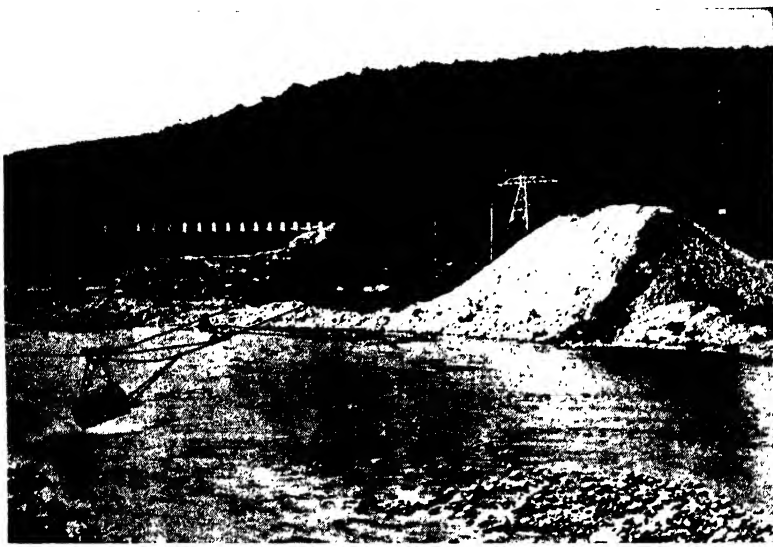


FIG. 55.—Slackline excavator digging river gravel and storing it on shore.

Excavators are generally adapted to cut to a depth of one-third of the span and lift the material 60 to 90 ft. above the top of the cut, depending upon the height of the excavator tower. The equipment consists of a drag bucket attached by chains to a carrier which runs on an inclined track cable (Fig. 55). The equipment is usually arranged so that the bucket runs back freely when the track cable is pulled up tight. At the desired point, the cable is slackened and the bucket, now pulled by the load cable, digs into the material until it is filled, when the track cable is again tightened and the loaded bucket rises and travels to the discharge point.

Table 17 gives the output of Sauerman excavators when digging sand or gravel at a digging speed of 200 ft. per minute, conveying

speed of 600 ft. per minute, and a gravity return speed of 1,200 ft. per minute.

TABLE 17.—CAPACITIES IN CUBIC YARDS PER HOUR OF SAUERMAN CABLEWAY EXCAVATORS

Span, feet	Average length of haul, feet	Size of bucket			
		1 yard	2 yards	3 yards	3½ yards
400	250	52	100	156	182
600	350	44	88	132	156
800	450	..	72	108	124
1,000	550	..	68	102	119

In the case of cableway drag scrapers the scraper is of the bottomless type and is not raised after it has filled but is permitted to continue its travel on the earth and the bank on which the earth is dumped. The track cable is supported at one end on a high head tower, containing the machinery and operator's cab, and at the other end by a low tailtower. The towers are mounted on railroad wheels or crawler tracks and powered to propel themselves forward as the work progresses. The scrapers are particularly suited for building levees or for excavating a channel where the material may be dumped directly on the bank. In levee construction the output of the machine depends on its span and the height of the levee. The span is usually 500 to 750 ft. and the digging and hauling speed 450 ft. a minute. The return speed on short spans by means of gravity is 1,800 ft. per

TABLE 18.—HANDLING CAPACITIES (THEORETICAL) OF CABLEWAY DRAG SCRAPERS
(Cubic yards per hour)

Average length of haul, feet	Size of scraper				
	4 yd.	6 yd.	8 yd.	10 yd.	12 yd.
100	320	480	640	800	960
200	168	254	336	420	508
300	112	168	224	280	336
400	86	126	172	213	252
500	68	104	136	172	208

minute or 1,400 ft. per minute when the back haul is powered. Table 18 gives estimated hourly capacities in cubic yards of different sizes of Sauerman scrapers operating in loose sand and gravel.

Hydraulic Sluicing.—This method of moving earth utilizes streams of water at high pressure directed at the material through portable nozzles usually called "hydraulic giants" or "monitors." The high-velocity jets are generally directed against the foot of the bank to undercut the material and the water sweeps it to waste or into sumps or sluiceways. As a rule the water carries about 10 per cent solids. Performance generally depends on the degree of compaction of the sand or gravel being sluiced, on the pressure of the water for cutting the bank, the quantity of water and slope of sluiceway for transporting the material, the location of the nozzle with respect to the bank, the nozzle design, and general operating experience. Usual operating pressure heads vary from 100 to 400 ft. and, except for the fact that a large quantity of water is required, plant costs are normally quite low. Table 19 indicates water requirements for average installation.

In Trinity County, California, a highway grading job was performed by means of hydraulic giants in moving 6,000,000 yd. of earth. The nozzles were exceptionally large, 7 and 8 in. in size, and water was supplied through a 26-in. line, branching to 18-in. lines which served the giants. A head of 550 ft. delivered 60 cu. ft. per sec. per 8-in. nozzle, and approximately 800 yd. per hr. was moved, the water carrying about 10 per cent solids.

TABLE 19.—WATER REQUIREMENTS, HYDRAULIC SLUICING

Nozzle diameter, inches	Discharge, cubic feet per second			
	Head, 100 ft.	Head, 200 ft.	Head, 300 ft.	Head, 400 ft.
2	1.60	2.25	2.75	3.25
3	3.60	5.10	6.25	7.25
4	6.50	9.25	11.25	13.0

Considerable care is required in the design and layout of the pumps. Sometimes it is advisable to provide a low-head pump

to augment the transporting power of the water. Where the material is sluiced into pipe lines it is possible to transport the mixture on as flat a grade as 1¾ per cent, while on ground sluices with planked sides a 4 per cent natural grade and sometimes as low as 2½ to 3 per cent, will carry the materials, which, depending upon their nature, may vary from 8 to 20 per cent of solids. In excavating clay, sharp nozzles such as 2½ in. at

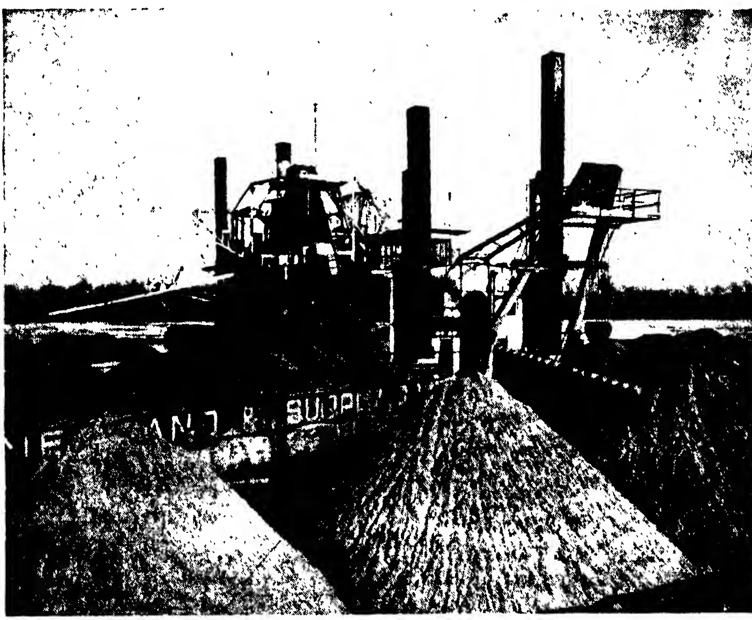


FIG. 56.—Ladder dredge with continuous bucket chain and self-contained screening plant for producing sand and gravel.

high pressures up to 400 ft. are effective in moving from 50,000 to 60,000 cu. yd. per month.

Dipper and Clamshell Dredges.—For subaqueous shallow excavating, such as channel deepening or other operations where it is necessary to remove rock or material containing large boulders, dipper, clamshell, or dragline dredges are commonly used, although their output in such materials is limited. In place of the cutterhead ladder (Fig. 57), such equipment carries a dipper stick or dragline boom. A 2-yd. machine will excavate about 100 yd. per hr., and a 4-yd. machine about 200 yd. per hr. Normally the capacities of this equipment are about one-half of equivalent dry excavation.

Ladder Dredge.—The ladder dredge is equipped with a powerful bucket elevator mounted on a steel ladder usually about 50 ft. long and extending down to the river bottom (Fig. 56). The end of the ladder may be raised and lowered for inspection. This type of dredge is particularly suited to digging gravel, which may be processed on the same unit. The equipment is usually large and expensive and, like most types of dredges, is not as a rule equipped with towing apparatus, a special towboat being normally used to move it. The ladder generally

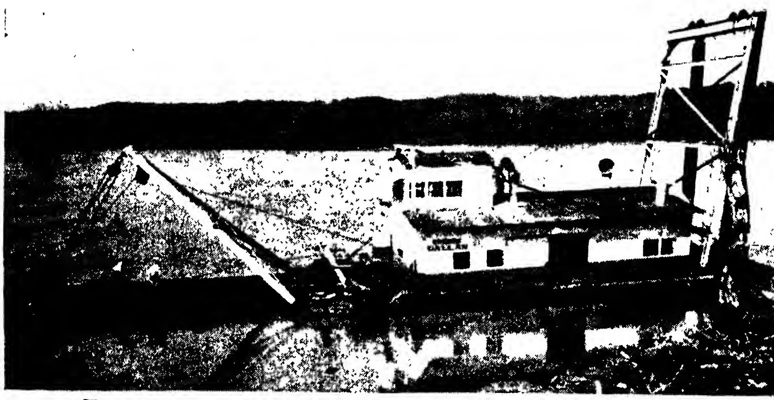


Fig. 57.—Suction dredge (16 in.) with motor-driven cutterhead.

travels at about 60 ft. per min., and with a capacity of 3 cu. ft. per bucket the output of the dredge is 100 cu. yd. per hour. A line of 5-cu. ft. buckets delivers 200 cu. yd. per hr. and one with 8-cu. ft. buckets, 350 cu. yd. per hr.

Suction Dredges.—The elements of an hydraulic suction dredge consist of an engine or motor-driven pump, mounted on a barge, and a suction line from the pump supported on a ladder and extending down into the subaqueous formation, this ladder being hinged for raising or lowering (Fig. 57). Some dredges are equipped with motor-driven cutterheads, which cut and churn the material prior to its entrance into the suction line. The discharge line is supported on pontoons and connects with the shore line, which runs to the desired discharge point. At the rear of the dredge steel spuds serve as pivots about which the dredge swings as it cuts into the material. The suction line is usually 3 to 4 in. larger than the discharge line to maintain a vacuum on the pump when discharging on a short pipe line.

Most dredges have a life of 15 to 20 years and, although invariably of special design, certain principles of general-purpose design should be employed to adapt the dredge to a wide range of work. The pumps and runners are made of special wear-resistant material.

TABLE 20.—SUCTION DREDGES—AVERAGE SIZES AND PERFORMANCES*

Discharge pipe diameter, in.	Average pump hp. ratings (for cutter and swing add 25 %)	Velocity for normal operation, ft./sec.	Max. length of horizontal pipe for one pump and heavy material, ft.	Normal output per month of 25 days at 24 hr. per day, cubic yards		
				Light material	Medium material	Heavy material
6	100	15	720	50,000	21,000	7,000
8	180	15	1,050	80,000	33,000	12,000
10	290	15	1,400	115,000	50,000	17,000
12	430	15	1,800	170,000	70,000	25,000
14	600	15	2,250	235,000	100,000	35,000
16	810	15	2,750	310,000	130,000	45,000
18	1,060	15	3,350	400,000	170,000	58,000
20	1,340	15	3.890	500,000	210,000	72,000
22	1,670	15	4,500	600,000	250,000	87,000
24	2,050	15	5,150	730,000	305,000	105,000
26	2,450	15	5,800	860,000	360,000	124,000
28	2,900	15	6,650	1,000,000	420,000	144,000
30	3,450	15	7,600	1,170,000	500,000	170,000

* This table represents average conditions and is largely relative. Specific problems must be analyzed in terms of local conditions and nature of material.

Under normal conditions the solids run from 8 to 15 per cent. As a general rule, the size of the solids determines the size of the pump, although when the capacity of larger pumps is not necessary it is more economical to use cutterheads with narrow slots, or a stone box ahead of the pump. The output of a dredge is exceedingly variable, depending upon the size and kind of material, the pipe-line size and length and static head, the suction pipe size and lift, and the available power. Table 20 gives some relative performance data for various sizes of dredges. On the Miami Conservancy District a 15-in. pump averaged around 300 to 400 yd. of gravel per hour, whereas the range was from 250 to 600 yd. per hr. Similar ranges of performance have

been reported by experienced operators. O. P. Erickson, of the Great Lakes Dredge & Dock Co., gives these figures:

A 26-in. dredge with 1,600-hp. pump in about 23 hr. pumped over a line 1,250 to 1,800 ft. long and with an 8- to 9-ft. rise, 53,000 yd. of sand and mud, but only 9,500 yd. when digging hard clay mixed with large clamshells. Similarly a 30-in. dredge with a 3,000-hp. pump was able to pump sand and mud a distance of 15,000 ft. but could pump gravel only 5,000 ft.

Among the precautions to take in starting up a new dredge is the necessity of an experimental run to tune up the unit, remove most of the normal difficulties, and determine the most efficient point of performance. Graphical records and instruments are particularly useful at various points on the equipment where efficiency is not readily detected otherwise, and performance charts should constantly be analyzed by competent personnel. The best speed and output relationship should be determined for a combination of conditions. Sometimes it may be necessary to change cutters to suit the material, and the correct speed of the cutter is of particular importance. Changing the size of the suction pipe may improve the output. Fort Peck experience indicates that a larger suction line and lower suction lift increased the output. A 35-in. suction was eventually used with a 28-in. discharge line. Velocities were also substantially increased over earlier practices, resulting in greatly improved dredge output. Dredge pipe lines are discussed more fully, in Chap. XV.

Considerable expense is justified in preventing excessive sizes of stone, wood, or other foreign particles from reaching the pump. An adequate supply of replacement parts, constantly available and properly timed for installation, is a major phase of dredge management.

Summary.—The reader is cautioned in the use of performance data presented in this chapter. Such data are intended to be relative, to give a reasonably comparative picture, but application to a particular job requires a full analysis of all local conditions. *Hourly* rates of output can seldom be maintained over more than a day. Such figures are important in laying out related plant units for balanced performance in a chain of operations, but the large list of variables which affect the output of excavating equipment often permits the *monthly* output to be only 50 to 70 per cent of the optimum ability of the plant.

CHAPTER XIV

TRANSPORTING EQUIPMENT

One great obstacle to a general understanding of transporting equipment for moving large volumes of earth, rock, or gravel lies in the variety of designations that are used in stating carrying capacity or output. The following story is typical of the confusion which sometimes develops.

In getting a new job organized, one shift was trying hard to beat the other in establishing the best daily output to serve as the "goal rate." At the end of the first day, the dragline runner came out and said, "Well, that's a good start in this stiff clay. We put out 2,420 yd.; I counted 1,210 loads on the 2-yd. bucket." The hauling foreman retorted, "That can't be right. The new wagons are rated at 10 yd., and we had 302 loads; that makes 3,020 yd. It only took four bucket loads to fill each wagon, but your buckets were heaping full."

The argument brought on a careful measurement of the wagon body, and it was found to have 7.8 yd. cubical volume. The foreman muttered, "Well, they advertise a 10-yd. wagon, but the only way you can get 10 yd. is by loading well compacted earth and piling it up high on the wagon. This clay makes big lumps and voids, so we probably have only 9 yd. per heaping load, or 2,718."

But even that wasn't right. The engineer's cross section of the pit showed 2,160 yd. bank or "pay" measure for excavation. The clay was hauled to the site of the earth dam and compacted as well as possible into still another yardage, namely, 2,250 yd. of *fill*. Altogether, the same volume of clay had been given five designations of yardage: 2,420, 3,020, 2,718, 2,160 and 2,250.

At present, excavator buckets and dippers are rated by cubical content, while hauling equipment is largely advertised on the basis of heaping full measure of uncompacted material. As a further inconsistency, railroad cars are rated at water-level capacity, or straight cubical content.

TABLE 22.—TRANSPORTING EQUIPMENT—GENERAL DATA

Type	Special advantages	Limitations			Size	Rated capacity per load		Rate of movement, miles per hour	Life of unit, economical hours of operation	Average costs			
		Weather	Material	Route: condition, type, maximum grade, etc.		Water level, cubic yard	Heaping full, cubic yard			Initial	Operating, per hour	Maintenance and repair per hour of operation	Total for average life of equipment per hour of operation
A	1	2	3	4	B	5	6	7	8	9	10	11	12
Tractor-drawn scrapers	Combined loading and dumping unit	Unsuited in rain or mud	Best suited to earth Can handle sand to heavy clay and loosened shale and gravel	Only general road maintenance required	Small	6	7.5	3	10,000	$8,400	$1.10 to $1.50	$1.15 to $1.45	$3.10 to $3.80
	Fast loading and dumping; no delay, can spread material at dump		Low output in sticky clay		Medium	8 12	9.5 15	3	12,000	10,500	1.30 to 1.70	1.40 to 1.70	3.60 to 4.30
	Can load, haul, and dump with only one operator		Scarifier may be required for solidly compacted material	Maximum grade 25 per cent on firm roadbed	Large	18 23	24 30	3	15,000	18,500	1.40 to 2.00	2.00 to 3.00	5.50 to 6.80
Trucks	High mobility	Poor going in rain or mud	Able to handle all types depending on body design	Requires special road maintenance	Small	4	5	26	10,000	2,500	0.90 to 1.30	0.65 to 0.95	1.80 to 2.50
	Adaptable to various types of hauling Single unit for power and load				Medium	8	10	11	12,000	5,000	1.20 to 1.70	1.40 to 1.80	3.00 to 3.90
	High-speed haulage and return Can back easily			Maximum grade 15 to 25 per cent	Large	12	15	8	12,000	8,000	1.40 to 2.00	1.80 to 2.20	3.90 to 4.90

Rubber-tired tractors and wagons (truck-wagons)	Fair mobility Can handle large loads Medium speed haulage and return Side, rear or bottom dumping available Can operate in tandem for long hauls Sharp turning radii	Poor going in rain or mud	Able to handle all types depending on body design	Fair road maintenance desirable but not essential Maximum grade 25 per cent	Small	6	7	9 to 11	10,000	6,500	1 20 to 1.60	0.95 to 1.25	2.70 to 3.40
					Medium	10	12	8 to 11	10,000	13,000	1 30 to 1 70	1.35 to 1.65	3 50 to 5 00
					Large	18	24	4	12,000	12,000	1 40 to 2 00	1 75 to 2 15	4.35 to 5 30
Crawler tractors and wagons	Fair mobility Can operate on soft and rough ground with large loads Side, rear or bottom dumping available Can operate in tandem for long hauls	Rain and mud reduce production	Able to handle all types depending on body design Bottom dump for earth; side or rear dump for heavy rock	Only general road maintenance required Maximum grade 25 per cent	Small	6	7 5	3 5	10,000	7,000	1 10 to 1.50	1.20 to 1.50	3 00 to 3.70
					Medium	10	13	3 5	10,000	8,000	1 30 to 1 70	1 40 to 1 70	3 50 to 4 20
					Large	15	18	3 5	10,000	11,500	1 40 to 2 00	1 75 to 2 15	4 30 to 5 30
Railroad trains	Effective high-speed and long-range haulage Economical haulage over a fixed route Electric systems avoid gases for underground service Low mechanical maintenance	No limitations	Able to handle all types depending on body design	Requires expensive rail and roadbed construction and maintenance Maximum grade depends on locomotive used Average maximum 3 per cent	Small	Locomotive 8-ton gas, two 6-yd. cars		4 to 5	20,000	8,000			
					Medium	Locomotive 30-ton Diesel, four 15-yd. cars		10 to 20	30,000	25,000			
					Large	Locomotive 90-ton steam or Diesel, seven to ten 30-yd. cars		15 to 30	30,000	Depends on size of train			

TABLE 22.—TRANSPORTING EQUIPMENT—GENERAL DATA.—(*Continued*)

Type	Special advantages	Limitations			Size	Rated capacity per load		Rate of movement, miles per hour	Life of unit, economical hours of operation	Average costs			
		Weather	Material	Route: condition, type, maximum grade, etc.		Water level, cubic yard	Heaping full, cubic yard			Initial	Operating, per hour	Maintenance and repair per hour of operation	Total for average life of equipment per hour of operation
A	1	2	3	4	B	5	6	7	8	9	10	11	12
Belt conveyors	Continuous and uniform haulage at high efficiency Low labor and repairs requirement	Unless covered, rain will decrease output seriously when handling earth or clay	Size of pieces is limited by width of belt and shape of rollers	Any route for which supports can be provided for the ends of the conveyor flights	Small	Belt width, 24 in., 300 cu. yd. per hr.		4.5	20,000	Depends on length	Costs depend on local installation requirements.		
	Can be supported on lightweight bridges, trestles, or suspension cables to avoid rough ground and long detours		Wet, sticky material is hard to handle	Maximum grade up to 40 per cent, depending on material	Medium	Belt width 36-in., 850 cu. yd. per hr.		5.7	20,000	Depends on length			
			Requires a special feeder		Large	Belt width, 60-in., 2,800 cu. yd. per hr.		6.8	20,000	Depends on length			
Aerial tramways	Carries material over rough, rugged terrain and over long distances	High winds hamper operations	In general, small buckets limit the material to small pieces such as crushed ore, sand, gravel, and similar material	Long spans and angles in the line are not desirable	Small	Bucket size, ½ yd.		5.5	30,000	Depends on length	In the case of trains, conveyors, tramways, dredge lines and the like, costs depend entirely on individual installations and local conditions		
	Avoids surface congestion of traffic				Medium	Bucket size, 1 yd.		5.5	40,000	1 mile long, cost about $62,000			
	Low labor requirements Can often carry load by gravity, requiring only a small amount of power to return the buckets			Maximum grade limited only by power available	Large	Bucket size, 4 yd.		5.5	40,000	Depends on length			

TABLE 22.—TRANSPORTING EQUIPMENT—GENERAL DATA.—(Continued)

Type	Special advantages	Limitations			Size	Rated capacity per load		Rate of movement, miles per hour	Life of unit, economical hours of operation	Average costs			
		Weather	Material	Route: condition, type, maximum grade, etc.		Water level, cubic yard	Heaping full, cubic yard			Initial	Operating, per hour	Maintenance and repair per hour of operation	Total for average life of equipment per hour of operation
A	1	2	3	4	B	5	6	7	8	9	10	11	12
Dredge lines	Subaqueous excavation High production from single digging unit	Storms, floods, and ice hamper the operations on the floating dredges	All types which can be broken by the cutter-head	Any route on which the pipe can be supported	Small	6-in., 15 to 45 cu. yd. per hr.		8.2 (12 ft. per sec.	50,000 to 75,000*	$ 25,000	Costs depend on individual installations and local conditions.		
	Especially suitable for moving and placing core material in hydraulic-fill dams as the discharge system permits the graded deposition of particle sizes	Can operate and place fill through ordinary rains and changes in water level	Size of pieces is limited by size of discharge line and the clearance in the pump	Straight line and constant grade layout is desirable	Medium	16-in., 140 to 425 cu. yd. per hr.		10 2 (15 ft. per sec.	50,000 to 75,000*	100,000			
					Large	30-in., 650 to 2,000 cu. yd. per hr.		11 5 (17 ft. per sec.	50,000 to 75,000*	1,000,000			

* Depends on materials being handled.

TABLE 23.—EXAMPLE OF COST ANALYSIS: LOADING AND HAULING 700,000 YD. OF EARTH
(Estimated output 70,000 yd. per month (average) for 10 months)

EQUIPMENT PERFORMANCE

2-yd. dragline:	
Bucket load (bank measure)	1.5 yd.
Cycle time	30 sec.
Output per hour (best)	180 yd.
Output per day of 22 hr. (practical) 180 yd. × 22 × 0.75	3,000 yd.
Output per month of 25 days	75,000 yd.
Tractors and wagons:	
Loaded haul	800 ft.
Capacity of 12-yd. wagons (bank measure)	9 yd.
Number of bucket loads per wagon	6
Time of loading and moving out	3.5 min.
Hauling at 3.5 miles per hour	2.6 min.
Return at 5.0 miles per hour	1.8 min.
Turning, dumping, and waiting	2.1 min.
Total cycle time per unit	10 min.
Number of trips per hour	6
Yards per hour at 9 yd. per load	54
Number of units required to haul 180 yd. per hr.	4
(This allows 36 yd. per hr. of spare hauling capacity)	

LABOR AND EXPENSE
(3 shifts)

	Rate	Cost per Month	
Loading labor:			
3 foremen	$1.50	$864.00	
3 dragline operators	1.00	576.00	
3 oilers	0.75	432.00	
3 tractor men	0.75	432.00	
3 grader men	0.60	345.60	
3 truck drivers	0.60	345.60	
			$2,995.20
Expense:			
Repairs		$1,000.00	
Fuel		151.60	
Oil and grease		120.00	
Cable		175.00	
			1,446.60
Hauling labor:			
3 foremen	$1.50	$ 864.00	
12 tractor men	0.75	1,728.00	
3 wagon winders	0.45	259.20	

Equipment

Cost of loading equipment:		
2-yd. dragline	$24,000.00	
48-in. elevating grader (used)	4,000.00	
Trucks (1/4 cost)	2,100.00	
75-hp. tractor	6,700.00	
		$36,800.00
Cost of hauling equipment:		
Four 75-hp. tractors	26,800.00	
Four 12-yd. wagons	13,140 00	
Miscellaneous tools	1,945.00	
Trucks (1/4 cost)	2,100 00	
		43,985.00
Depreciation per month on basis of 10 months' use:		
Loading	3,680.00	
Hauling	4,398.50	
Total monthly equipment cost (disregarding salvage on equipment)		8,078.50
		$8,078.50
		12,182.60
Monthly cost		$20,261.10
Monthly output		70.000 yd.

This cost is exclusive of superintendence, overhead. interest, bond, etc.

3 greasers	0.60	345.60	
3 greaser helpers	0.45	259.20	
3 mechanics	1.00	576.00	
3 mechanic helpers	0.60	345.60	
2 electricians	1.00	384.00	
2 welders	1.00	384.00	
2 welder helpers	0.50	192.00	
3 waterboys	0.45	259.20	
			5,596.80
Expense:			
Repairs		$1,025.00	
Fuel		549.00	
Oil and grease		475.00	
Miscellaneous supplies and tools		95.00	
			2,144.00
Total monthly labor and expense			$12,182.60

Cost per yard $\dfrac{20,261.10}{70,000}\Big\}$ 28.94 cts.

A further important element in job planning for transporting equipment lies in proper arrangement for disposal of material. Where it is hauled to a dump, the layout of the dump and organization of dumping operations deserve considerable study, and sufficient dumping points should be maintained to avoid confusion or time loss in waiting to dump. Again, if disposal is to a fill, the fill should be maintained with enough leveling and tamping equipment to prevent waiting by hauling units. Similar requirements are needed for stock-piling by providing sufficient handling equipment and preventing the accumulation of carelessly dumped material. Where a transfer is made from one type of transporting equipment to another as, for example, from conveyors to trucks or wagons, it is generally more practical and economical to build suitable surge bins from which loading is fast and easy and by means of which intermittent production is equalized.

Selection of Equipment.—Important factors to be considered in making a selection of equipment (see Table 22) are: (1) the cost of owning and operating the loading and hauling equipment; (2) the pay load that can be delivered by the hauling unit, due consideration being given to grade, traction, maintenance, and the many other variables that affect output; (3) the round-trip time cycle of a hauling unit (which includes loading, hauling, dumping, and return time); (4) the number of units per hour that can be loaded by the loading unit, with proper allowance for exchange time of hauling units and time loss by delays that seem unavoidable. Many operators, to overcome time losses by delays, figure a 50-min. hour instead of a 60-min. hour when estimating jobs. The key equipment is usually the loading unit. The larger the hauling unit, the greater is the production of the loading equipment; and the less time is lost in exchanging hauling equipment; but this principle reaches its limit when the higher speed of smaller units on long runs becomes a factor to offset loading delays.

Needless to say, there are many jobs where a proper analysis of equipment would materially decrease the cost per yard. It is quite natural that many times an operator endeavors to make the job fit the equipment, whereas a small additional investment would make the equipment fit the job, and in many cases the saving would entirely cover the cost of the necessary new equipment.

TABLE 24.—SAMPLE ANALYSIS OF EARTH-MOVING COSTS FOR VARIOUS TYPES OF LOADING AND HAULING EQUIPMENT

Case	Loading equipment	Hauling equipment				Output of plant per hour cu. yd.	1,000-ft. haul			3,000-ft. haul			5,000-ft. haul		
		Type	Speed maximum m.p.h.	Pay load per unit cu. yd.	Cost per hour per unit		Cu. yd. per hour per unit	Number of units	Cost per cu. yd.	Cu. yd. per hour per unit	Number of units	Cost per cu. yd.	Cu. yd. per hour per unit	Number of units	Cost per cu. yd.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	2-yd. shovel or dragline; cost, $8 per hr.	75-hp. tractor and large wagon	5.3	15.0	$4.25	200	66	3	$0.105	34	6	$0.164	23	9	$0.224
B		75-hp. tractor and wagon	5.3	8.5	3.75	200	53	4	0.108	26	8	0.182	17	12	0.260
C		Truck	13.5	5.5	3.50	200	48	4	0.115	30	7	0.154	22	9	0.200
D	48-in. elevating grader; cost $6.50 per hr.	75-hp. tractor and large wagon	5.3	15.0	4.25	350	78	4	0.075	37	9	0.134	25	14	0.189
E		75-hp. tractor and wagon	5.3	8.5	3.75	350	60	6	0.090	27	13	0.158	18	19	0.223
F		Truck	13.5	5.5	3.50	350	54	7	0.095	32	11	0.128	23	15	0.171
G	Scraper	Tractor	5.3	7.5	3.80	200	56	4	0.068	25	8	0.152	16	13	0.238

Economics of Hauling Equipment.—A sample method of computing hauling costs is given in Table 23. This kind of analysis should be made for various types of equipment and different combinations which may be finally tabulated into something like Table 24, which is a sample analysis of comparative hauling costs.

In preparing an analysis such as in Table 24, special allowance should be made for lost time, speed, and grade in setting up the time table for determining average output. Likewise great care should be exercised in setting up loose measure in relationship to bank measure to keep these on a consistent basis. Following are some of the conclusions which may be drawn from Table 24 *for one particular set of conditions:*

1. The shovel layout costs more than the elevating grader or scraper system and is slower.
2. On short hauls the scraper is cheaper than the elevating grader system, even with very large hauling units, which, furthermore, are not very flexible and have limitations as to range of application.
3. On long hauls the scrapers cost more than tractors and wagons on account of the higher equipment cost, since a heavier tractor is needed to load a scraper as compared with pulling a free-running load.
4. The smaller tractor units appear to be less economical than the larger but slower units, except for short hauls.
5. Trucks are most economical for long hauls because of their greater speed.

Crawler Tractors.—Crawler tractors have been generally adopted for moving units for bulldozers, scrapers, wagons, buggies, etc., especially for rough roads or poor traction; their maximum speed is generally about 6 miles per hour, and they average more nearly 3 to 3½ miles per hour and are best suited to short hauls of 200 to 1,500 ft., although in some cases they may be employed on considerably greater distances. Their special advantage lies in their ability to travel over very rough surfaces and to climb steep grades up to 25 to 29 per cent at 1.7 miles per hour, which means that they can rise at the rate of 30 to 40 ft. per min. Where vertical lift is a big item, they get up faster, which is something that cannot be done so readily with trucks running on flatter grades.

The modern trend is toward oil-burning or Diesel engines. Such units, as compared with gasoline engines, use approximately one-half as much fuel and the fuel cost per gallon is approximately 50 per cent less than gasoline. In other words, the use of oil-burning engines saves approximately 75 per cent of what would be expended by the use of gasoline. Economies are also found

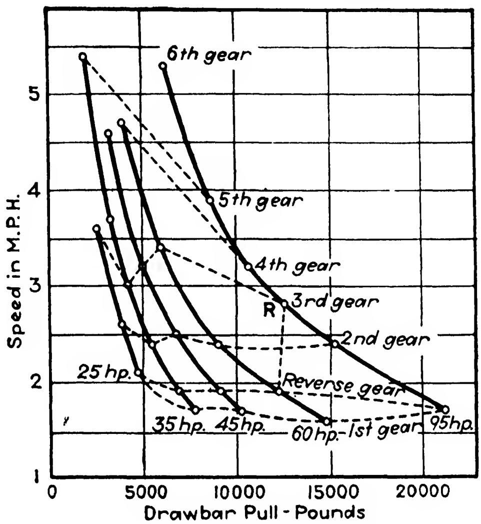


FIG. 58.—Typical speed range of standard crawler tractors.

in less loss from evaporation and pilferage. When the job is in remote sections, a decided saving in the cost of transportation and reduction in fire hazard are also obtained. The following table gives a comparison of fuel costs per hour of 75-hp. tractors:

	Gasoline tractor	Diesel tractor
First cost	$4,750.00	$6,500.00
Fuel, gallons per hour	8	5
Cost of fuel per gallon	0.11	0.07
Cost of fuel per hour	0.88	0.35
Saving per hour	....	0.53

Assuming the life of tractors at 10,000 hr., which is a reasonable estimate, the reduction in fuel cost with a Diesel tractor during that period would be $5,300, or almost the first cost of the tractor.

TABLE 25.—COMPARATIVE SPECIFICATIONS OF LARGE DIESEL TRACK-TYPE TRACTORS*

Manufacturer		Allis-Chalmers Manufacturing Co. (General Motors Engines)			Caterpillar Tractor Company				Cleveland Tractor Company (Hercules Engines)			International Harvester Company		
Size		HD-14	HD-10	HD-7	D-8, low gear	D-8, standard gear	D-7	D-6	FD	DD	BD	TD-18	TD-14	TD-9
Drawbar hp		108	79	54	97.91	95.84	75	44.75	96.9	61.19	38.05	70.59	53.5	38
Maximum drawbar pull and travel speed at rated engine speed:														
First gear	Lb.	24,600	18,430	11,500	26,111	20,485	20,100	9,692	21,831	11,816	8,013	18,973	13,500	9,000
	M.p.h.	1.72	1.69	1.84	1.4	1.7	1.4	1.7	1.61	1.7	1.84	1.5	1.5	1.5
Second gear	Lb.	19,250	14,800	8,150	18,740	14,529	12,300	6,524	12,450	10,022	5,556	13,357	9,750	6,500
	M.p.h.	2.18	2.06	2.55	2.0	2.4	2.2	2.5	2.75	2.3	2.64	2.0	2.1	2.2
Third gear	Lb.	14,900	11,100	5,800	15,580	12,337	8,200	4,714	8,584	7,596	4,127	10,561	8,000	4,300
	M.p.h.	2.76	2.68	3.45	2.3	2.8	3.2	3.2	3.66	3.1	3.46	2.5	2.5	3.2
Fourth gear	Lb.	11,400	7,500	3,000	13,344	9,968	5,100	2,939	5,468	4,568	2,000	7,827	5,750	3,400
	M.p.h.	3.50	3.78	5.82	2.7	3.2	4.6	4.6	5.0	4.9	5.4	3.30	3.4	3.9
Fifth gear	Lb.	8,700	5,850	......	10,713	8,058	3,500	......	......	......	......	5,157	3,750	2,250
	M.p.h.	4.36	4.62	......	3.2	3.9	6.0	......	......	......	......	4.6	4.8	5.3
Sixth gear	Lb.	4,500	4,100	......	7,524	5,594	......	......	......	......	......	3,833	2,850	
	M.p.h.	7.00	6.03	......	4.3	5.3	......	......	......	......	......	5.70	5.8	

Reverse speed, m.p.h.	2.0 and 3.2	1.86 and 4.17	2.19	1.4 and 2.3	1.7 and 2.8	1.6 2.6 3.8 5.4	1.9	1.58 and 2.82	2.0 and 3.65	1.8 and 3.4	1.5 and 3.3	1.5 and 3.4	1.7
Engine:													
No. of cylinders	6	4	3	6		4	3	6	6	6	6	4	4
Piston displacement, cu. in.	425	284	212.2	1,246		831	623	707	474	298	691	460	334
Governed r.p.m. at full load	1500	1600	1500	850		1000	850	1300	1200	1400	1200	1300	1400
Ground clearance, in.	13.5	11.6	10.4	10.5		15.5	10.12	16.5	13.5	13.25	14.5	11.75	10.13
Center to center track gauge, in.	68	62 or 74	63 or 52	78		74	56 or 74	69	61 or 48	52 or 44	62 or 74	56 or 74	44 or 60
Approx. shipping weight, lb.	27,800	20,700	13,000	33.110		23,500	15,820	28.250	13,700	8,800	22,000	15,500	9,850
Area of ground contact, sq. in.	3,759	2,775	2,144	3,905		3.357	2,392	3,840	2,392	1,764	3,046	2,504	1,664
Capacities:													
Crank case, qt.	14	13	8.5	27		22	14	24	16	12	22	16	11
Transmission case, qt.	40	24	21	40		40	20	144	52	36	30	24	15
Final drive, each, qt.	8	8	4	26		24	10	total	total	total	5	2.5	1.5
Fuel tank, gal.	68	44	31	69		65	45	60	30	24	60	45	31
Approximate fuel consumption at rated drawbar load:													
Hp.-hr. per gal	......	......	......	13.34	12.02	......	11.51	14.0	......	......	12.63		
Lb. per hp.-hr.	......	......	......	0.525	0.578	......	0.611	0.499	......	......	0.555		

* Gasoline and smaller type tractors not included in this table. Data subject to change with new models.

Diesel power is now being extended in its use to shovels, compressors, locomotives, pumping plants, and light plants on construction jobs. It is meeting with such universal favor that within a few years it will very largely, if not entirely, replace gasoline power on such work.

Table 25 gives the principal data for various makes of tractors, and Fig. 58 shows graphically the speed range and drawbar pull for representative sizes of tractors.

Bulldozers.—In Chap. XIII a general description of bulldozers as earth-moving devices was given, together with a table of output. The average cost of hauling dirt in wagons from a shovel on a 250-ft. haul is approximately twice the cost of moving this material the same distance with a tractor and bulldozer. This unit is particularly good on short distances up to about 200 ft., and it generally pays to investigate bulldozers for prime earth movers on short-haul cut-and-fill jobs. Bulldozers, of course, are indispensable in keeping an excavation dump or disposal area shaped up in order to permit other types of hauling units to maneuver at their maximum speed.

Tractors and Scrapers.—The tractor and scraper is a self-contained unit that is both a loading and hauling outfit and designed primarily for short-haul work. It can also be used for a variety of odd jobs such as stripping, grading, leveling, and trimming. Plowable materials are best suited for scraper work; sand will not readily climb into the scraper. One or more units can be used independently on a job. In dumping, a scraper spreads the load evenly. Wherever it is practical to use scrapers, moving earth with them offers special economies by eliminating the investment in loading equipment, and sometimes, also, the investment in a bulldozer or grader for spreading the material. Hence, on jobs for which they are adapted, scrapers are at present the best earth movers known.

The more conventional pneumatic-tired scraper is built in three representative rated sizes, a 6-yd. unit to be used with a 40-hp. tractor, an 8-yd. unit to be used with 50- or 60-hp. tractor, and a 12-yd. unit to be used with a 75-hp. tractor. The pay load of these scrapers runs from 60 to 80 per cent of the rated capacity, depending on the material being handled.

The modern development of even larger capacity scrapers for earth moving has been one of the outstanding events in construc-

tion-equipment design. Types and models have changed rapidly as experience dictated redesigns and improvements and as the demand for larger and larger capacities developed. One of the principal factors contributing to the rapid development of scrapers has been the introduction of heavy-duty rubber tires in exceptionally large sizes and capable of withstanding the severe service to which construction equipment is subjected. Large tires not only can travel over softer ground because of their large bearing surface, but under all conditions the tractive

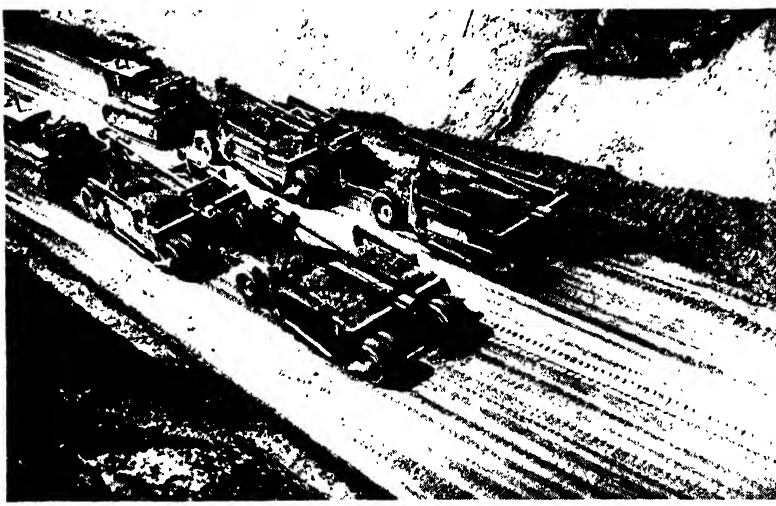


FIG. 59.—Pneumatic-tired scrapers in tandem pulled by heavy tractors.

effort is reduced. Furthermore, maintenance on equipment is reduced by absorbing the shock in rough going.

Most of the large single-bucket scrapers have a 10-ft. cutting blade, which is about as wide as can be handled over narrow roadways or on railroads for shipment from job to job. Additional capacity has largely been obtained by increasing the length of the bucket and to some extent the height. The loading of longer buckets is more difficult and calls for the material to travel a considerable distance in the bucket. Many materials do not accommodate themselves to this requirement and this has resulted in telescoping buckets being used which expand as the load is taken on. This construction is generally found on scrapers having a level capacity of 14 yd. or more.

There are various makes and types of scrapers which, because of the newness of this type of equipment, have been only slightly standardized. Some digging and dumping mechanisms are operated from special power take-offs on the tractor by cables, others by hydraulic pressure, still others by air pressure; in some types separate power units may be attached directly to the scrapers.

In some applications the use of two nominally sized scrapers offers a more flexible plant setup than the use of larger single units. The efficient use of tandem units (Fig. 59) begins for distances ranging from 700 to 1,000 ft. hauling on up. For a 700-ft. haul the yardage handled can be increased about 30 per cent with a tandem outfit whereas with a 2,500-ft. haul increased yardage has in some instances amounted to about 80 per cent. The greater capacity increase occurs with longer distances because fixed elements of time consisting of loading, spreading, and turning at both ends represent a smaller proportion of the total cycle, and the increased production is obtained at only an additional hourly investment charged against the second scraper.

The following data are representative of scraper performance and show the conditions of cycle time, hourly production, and cost per cubic yard which go into the estimating of this class of work:

CYCLE TIME IN MINUTES FOR SCRAPERS
(From field observations)

	12-yd. Scraper	Two 12-yd. Tandem Scrapers
Dumping	0.46	0.95
Loading	1.18	2.03
1,140 ft. travel loaded	2.39	3.13
1,350 ft. travel empty	2.99	3.55
Total cycle	7.02	9.66
Trips per hour	9.06	6.50
Cubic yards per hour net	57.7	87.4
Total operating costs per hour	$4.75	$5.75
Operating cost per cubic yard	$0.075	$0.063

These costs are from a particular job. Table 26 gives repre-

sentative cost data for a 12-yd. scraper and tractor for various haul distances and includes both operating and investment costs (compiled from R. G. LeTurneau data).

TABLE 26.—PERFORMANCE OF 12-YD. TRACTOR AND SCRAPER AT 80 PER CENT EFFICIENCY

One-way haul, feet	Cubic yards per hour	Minutes per round trip	Cost in cents per cubic yard at various hourly cost rates		
			$4	$5	$6
300	116	3	3.5	4.2	5.2
600	70	5.5	5.6	7.0	8.6
900	50	7.8	8.0	10.0	12.0
1,200	40	10.2	10.2	13.0	15.2
1,500	32	12.7	12.7	15.5	18.5
1,800	27	15	15.0	18	21
2,000	22	17.4	17	21	25

The selection of the correct size and type of scraper is a matter of sound judgment and experience because each material has its own characteristics, which must be properly considered in selecting the correct cutting edge, capacity, and tendency to load into a deeper scraper. Ordinarily it takes about 1 min. to load a scraper regardless of the amount of power introduced.

The correct combination of tractor and scraper is also important. It is not enough to merely state that a tractor has enough drawbar pull, but it also must have enough weight and contact area with the ground to develop this full drawbar pull under a variety of underfoot conditions. The questions of balance in the tractor, contact area, and uniformity of traction are all important factors.

One factor which is likely to be misinterpreted or underestimated, much to the distraction of the contractor, is the amount of swell in the material when it is picked up and put into a scraper; for example, sand and clay have entirely different characteristics. Sand may swell only 5 to 15 per cent, whereas clay might swell from 50 to 60 per cent. It will naturally take considerably more trips to handle clay, which swells a large amount, as compared with sand having relatively low voids. This factor alone accounts for wide variations in performance

of the same equipment on different jobs and makes comparisons difficult. It may also be an important influence in selecting equipment for a job.

On one job careful measurements were made of a large number of loads of red clay carried in a 12-yd. scraper. The clay weighed 96 lb. per cu. ft. This was later compared with careful cross sectioning of the pit from which the material had been removed, and it was found that the 12 yd. of loose measure in the scraper actually represented 7 yd. of solid pay measure on the average. Another check was made with an 18-yd. scraper and the pay measure was found to be 10½ yd.

As larger scrapers were introduced, the power required for loading them increased and eventually led to the introduction of a second tractor at the loading points which is used as a pusher for assistance during the period of loading. This allows working in harder materials and also results in increased loading of the scraper.

The best results are obtained by using a scraper with enough capacity to take all the dirt that two tractors, one pushing and one pulling, can shove into the scraper. Further advantages are obtained by developing the borrow pit so that loading is always on a downgrade of about 6 per cent. A pusher and pulling combination becomes economical for long hauls with scrapers having a capacity of about 18 yd. level and 23 yd. heaped. Further benefits in this respect are obtained by using special low-gear tractors to introduce additional tractive effort.

On short hauls the speed of travel is a relatively less important factor than other abilities of the equipment. For example, the use of trucks is less of a factor even though they have a high speed rating, because the equipment has no opportunity to develop its inherent speeds. On many jobs a tractor and scraper combination can deliver about as much dirt up to 1,000 ft. of haul as can a trucking system. In the end it is the average speed over a complete cycle which counts and not any instantaneous running speed, and the related working conditions are very important factors in this respect.

Pneumatic-tired Tractors and Scrapers.—A number of different machines running on tires have lately been developed which are intended to incorporate the advantages of self-loading scrapers with the high speed of trucks. The large units of this

type (Fig. 60), which have been used in the past few years at Hansen Dam, were loaded by four separate sources of energy, *viz.*, the power in the rubber-tired pulling unit, which is generally considered part of the high-speed scraper unit, the power in a pusher tractor, the power in a quickly engaged snatch tractor, which applied additional pulling effort at the front, and the influence of gravity by having the loading done downgrade. All these factors were necessary because the material being

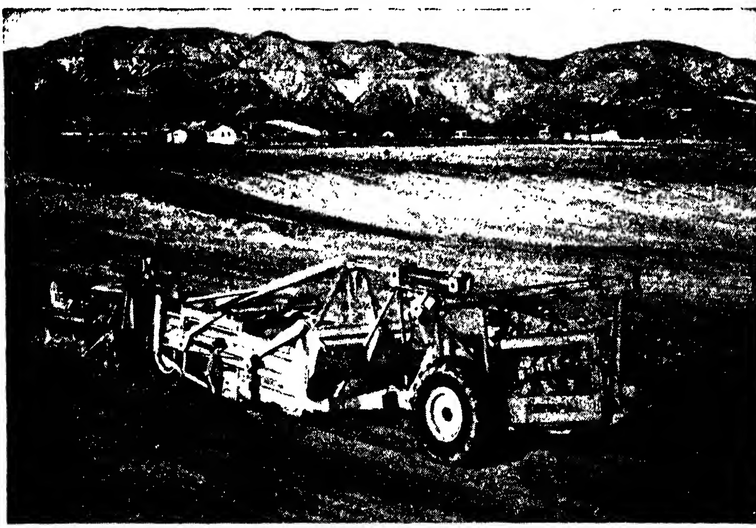


FIG. 60.—Rubber-tired tractor and scraper, capacity 22 cu. yd., water level, being assisted during loading by pusher tractor.

loaded was of a sandy nature which would cause the wheels of any one unit to spin in the sand and not develop sufficient contact to introduce motion; in other words a large amount of contact area was required. The range of speeds on this unit runs from 1.7 first gear to nearly 18 miles in sixth gear giving a ratio of about 10:1, whereas the normal truck ratio is 5:1.

The ultimate in high-capacity and high-speed rubber-tired earth-moving equipment has probably not been reached, and manufacturers are at present talking of units capable of carrying 20 to 25 yd. of pay load up a 5 per cent slope at speeds as high as 10 miles per hour. This will require engines in the pulling units with capacities of 250 to 300 hp.

For efficient production it is necessary to plan a careful routing of the units to avoid traffic interference, and ample provision should be made for turn-around space at the dump or pit. Sufficient digging area is also essential. To decrease waiting time, it is often desirable to provide different out and back routes.

One of the most important factors for rubber-tired equipment is the maintenance of adequate roadways. The two go hand in hand, and such maintenance must be on a day-to-day basis of continuing expense. Most of the elementary principles of good highway practice must be utilized such as good alignment, easy curves, superelevation, easy grades, smooth surfaces, ample width for passing, and proper dust control. On one job the benefits to production were increased to such an extent that it paid to have two roadways, one of which was being scraped and watered while the other one was in service. The machines in the larger capacities are of tremendous proportions, and anything that causes severe impacts or shock loading in their parts leads to expensive repairs and frequent shutdowns. As one contractor put it, after trying to operate under the usual rough construction-road conditions:

> After a month of operation I figured out my daily repairs, replacements, tire cost, and outage time expense, and found that I could maintain a very good highway for half the price of the repair costs and recover the additional production due to less outage time as pure "gravy."

Wherever scraper outfits can be used owing to the type of material, topography of the job, and other controlling conditions, earth can generally be moved at a cost of 3 to 4 cts. less than is incurred by the earlier operation of shovel and trucks.

At average hauls of 500 ft., hauling can be done at a cost of from 5 to 8 cts. per cu. yd. The loading time runs from 45 to 90 sec., and the loading distance from 30 to 120 ft., depending on the nature of material and depth of cut. The dumping time varies from 15 to 60 sec., depending on the nature of material and spreading requirements at the dump. A 12-yd. scraper making a 4-in. cut fills in about 100 ft.; it will deposit a layer of 3 to 6 in. or up to 1 ft. or more in thickness.

Table 27 shows representative outputs of scraper outfits in common earth, giving the pay load in yards per hour.

TABLE 27.—SCRAPER OUTPUT IN COMMON EARTH*
(Pay yards per hour; 55-minute hour)

Scraper capacity, cu. yd.		Loading grade	Tractor pulling	Tractor pushing for loading	Distance of haul, one way									
Heaped	Struck				400	600	800	1,000	1,200	1,500	2,000	3,000	4,000	5,000
12	10	Level	Low-geared D8	None	131	104	85	72	63	53	41			
12	10	Level	Low-geared D8	Low-geared D8	147	114	93	77	67	55	43			
12	10	−5%	Low-geared D8	None	142	110	91	79	69	58	46			
12	10	Level	Low-geared D8	Low-geared D8	...	192	158	135	117	99	78	55	42	34
(2 in tandem)	(2 in tandem)													
18	14	Level	Low-geared D8	None	137	109	89	76	66	55	43			
18	14	Level	Low-geared D8	Low-geared D8	179	140	114	96	83	70	54	37		
18	14	−5%	Low-geared D8	None	155	123	100	86	75	62	49			
23	18	Level	Low-geared D8	Low-geared D8	...	173	141	120	105	87	68	48	36	
30	23	Level	Low-geared D8	Low-geared D8	...	...	180	154	133	111	87	61	47	37
30	23	−5%	Low-geared D8	Low-geared D8	...	...	191	162	140	117	92	64	49	40

For dense clay reduce output about 10 per cent.
For sand reduce output about 5 per cent.
* Data by R. G. Le Turneau Co.

An important rule to keep in mind in selecting transporting equipment is that either the job must be large enough to justify planning for a particular equipment setup and maximum production, or the equipment should be selected for a variety of conditions and at times used in places where it is not best suited but with a definite over-all economy in the average contractor's work. These two principles will not mix.

Fig. 61.—Tractor-drawn side-dump crawler wagon, 10 cu. yd. capacity.

Tractors and Wagons.—Practically all wagons are rated in heaped loose measure, and the pay load is usually about 75 per cent of the loose measure. Before the advent of rubber-tired equipment, crawler wagons were used almost universally and their capacities range from 6 to 10 yd., water level, their size growing as the size of tractors grew. Most wagons are designed with low clearance for easy loading with elevating graders. The bottom-dump wagons are best suited for earth or rock free of large sizes, whereas heavy rock is usually best handled in side-dump wagons (see Fig. 61). Occasionally it is possible to operate two wagons in tandem on longer hauls, but more recently it has been found cheaper to use single wagons at higher speed. Typical capacities of wagons are: A 12-yd. rated wagon has a water-level capacity of 8.07 cu. yd.; a well-known 15-yd. wagon has

9.5-yd. water-level capacity; while a flared-side wagon with a rated capacity of 13 yd. actually carries $9\frac{1}{4}$ yd. at water level. The most important item of maintenance on crawler wagons is to keep the wheel or tread alignment accurate at all times.

For a 500-ft. haul, earth can be moved by tractors and wagons for about 9 to 11 cts. per cu. yd. This equipment, however, with large wagons is suited to hauling distances up to 4,000 or 5,000 ft. and sometimes greater, especially where the road maintenance,

FIG. 62.—Tractor-drawn wagon, 18 cu. yd. capacity, with pneumatic tires and hydraulic brakes.

owing to weather, would be too high to provide a good road surface for smaller high-speed trucks.

Tractors and Pneumatic-tired Wagons.—The recent trend has been toward wagons using large pneumatic tires (Fig. 62) which have made easier hauling for the tractors and thereby have allowed the use of larger units. Pneumatic-tired wagons range in size from 6 to 12 cu. yd., water level, and are cheaper to operate than crawler wagons because the expense of repair to crawler treads is eliminated.

To meet the demand in a particular field, some unusually large so-called "buggies" have been developed with capacities of 24 to 30 yd. loose heaped measure, which run about 18 and 23 yd. water-level measure, respectively, and are designed for operation with 75-hp. tractors. The buggies are mounted on 16 rubber tires, and the large size is of advantage in permitting the use of

large loading units, which allows them in turn to handle large pieces of rock. The construction of the buggy is very simple—the body merely sliding back to dump the load, and such dumping may be accomplished while the unit is in motion.

Prices of Tractors and Equipment.—The following are representative pieces of tractors and tractor-drawn equipment:

35-hp. tractor (Diesel)	$4,500
50-hp. tractor (Diesel)	6,000
75-hp. tractor (Diesel)	7,000
8-yd. water-level crawler wagon	3,000–3,500
Bulldozer	1,500
12-yd. (rated) scraper	5,500
8-yd. (rated) scraper	4,500
6-yd. (rated) scraper	3,900
30-yd. water-level buggy	8,300
23-yd. water-level buggy	7,225
18-yd. water-level buggy	6,700
7-yd. water-level truck-wagon, comp	6,700

Linn Tractor or Truck.—The Linn truck is in general type similar to an ordinary truck, except that it has a tractor-type crawler unit on the rear axle in place of wheels. The body, placed directly over the crawlers, gives traction proportional to the load carried. It does not have the speed or capacity of pneumatic-tired equipment which is especially designed for production work, but it is an excellent service unit and particularly useful in bad weather. The Linn wagons range in size of body as follows: 8-cu. yd. body carries 5½ to 6 yd. pay dirt; 14-cu. yd. body carries about 10 yd. pay dirt. They travel at a maximum speed of about 12 miles per hour, and most machines are designed with four-speed reverse transmission, while some have five speeds each way, giving them the special advantage of operating satisfactorily in shuttle service back and forth, thereby saving the time of turning. It is possible to maneuver the unit up grades as steep as 40 per cent. Recently a new type has been developed with both rubber-tired wheels and crawlers on the rear axles, and the truck can be made to run on either set to meet road conditions by throwing a lever.

Trucks.—Truck haulage is becoming increasingly popular on construction projects, and one need only to recall earlier representative jobs where all earth and rock excavation was handled by railroad trains, with tracks scattered all over the place, to

appreciate the remarkable changes that have been brought about by trucks within the last decade.

Trucks of all sizes, types, and speeds are offered to construction men, with tonnage ratings that mean very little, and when to this confusion the stress of competitive selling is added, it is small wonder that it sometimes takes months and a long series of breakdowns to determine what the equipment really can do. Trucks range in size from ½ to 25 yd. cubic capacity, and are most commonly equipped with rear dump bodies. They are

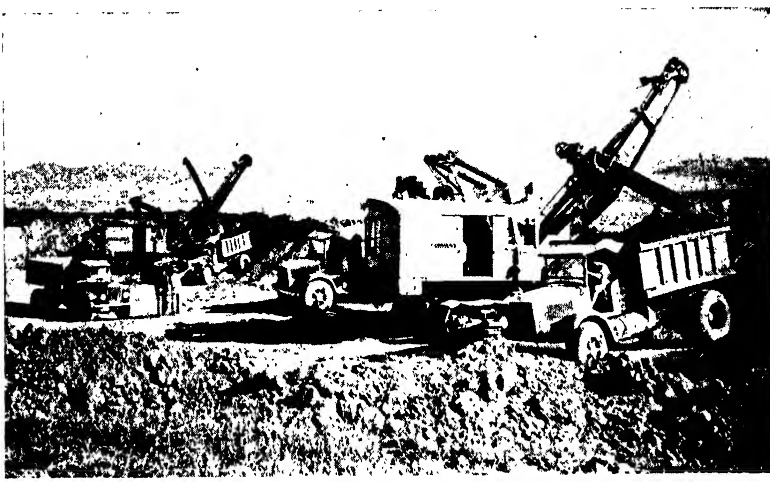


Fig. 63.—Shovels loading trucks on short swing; 7,000,000 cu. yd. of earth moved 2½ miles by fleet of 30 8-yd. trucks using butane gas.

considered essentially high-speed hauling units, having average speeds of 5 to 30 miles per hour, depending upon size and road conditions, with top speeds, empty, of 15 to 50 miles per hour. Recent developments in special-size tires have increased the speed of travel. The bodies are usually of special sturdy design and shape, with either open ends or special dumping gates (Fig. 63). Dumping is usually actuated by hydraulic hoists; many mistakes in equipment selection come from using slow-speed hoists or short-travel hoists, which do not bring the body to a steep enough dumping angle to empty the body clean.

Truck bodies of aluminum have come into wider use because of the greater pay load that can be carried as a result of the reduction in dead weight. For example, in one case a 12-yd.

water-level aluminum body weighed 5,120 lb., whereas a 10-yd. water-level steel body weighed 11,180 lb.

Selection of trucks begins by proper adaptation to the loading unit and must take account of the proper relationship between power and tonnage rating of chassis, size of body, weight of material, and volume of material loose and in bank measure. Small trucks are practical for loading with an elevating grader when the cabs are removed, but the loss of time exchanging the trucks under the carrier is so great in proportion to the capacity of the trucks that it decreases the production of both elevating grader and trucks. Large trucks can be loaded by elevating graders by removing the cabs, but these trucks are, in most cases, too high or too wide to load economically, and the average driver, being so close to the end of the conveyor, very seldom gets a full load.

One of the chief advantages of trucks is their great utility for other job purposes. Where good roads or routes are maintained, there is practically no limit to their economical range.

In laying out a large truck-haul job, careful planning of the work and preliminary preparation will pay large dividends. Routes should be carefully graded, all humps should be cut off, cuts should be properly located, and assignments of trucks to various shovels or loading units should be made to maintain a constant traffic stream. Special traveling foremen, dispatchers, "traffic cops," and servicing trucks with parts, air, gas, oil, and water are indispensable features of large-scale operations.

One of the most important elements of truck operation is the so-called "preventive maintenance" and inspection at regular intervals. The mechanisms must be kept tight at all times. It doesn't pay to wait for breakdowns to make repairs.

An outstanding truck-hauling job was the stripping of the base for Fort Peck Dam. A total of 4,100,000 yd. was moved in 120 days, using nine elevating graders, three shovels, and three draglines for loading into 250 light, fast dump trucks (mostly of 3-yd. capacity), running at speeds up to 40 miles per hour on return. On the best day of two 7-hr. shifts, 55,000 yd. was loaded by the graders. The hauling distance ranged from 7,500 to 9,000 ft., and the contract price for stripping and hauling was 31.5 cts. per yard. The truck hauling on the site of the New York World's Fair is another outstanding example of large-scale operations.

Dumptors.—A special pneumatic-tired high-speed truck known as the "Dumptor" has the unique feature of dumping on the front side and is best suited to short hauls where a shuttle movement is advantageous. The unit has three speeds each way at equal rates, making it possible to eliminate all waste time in turning, and thereby relieving the traffic problem in congested areas. It is capable of handling a maximum load of 5½ yd., and the speeds in low, second, and high are rated, respectively, at 4½, 8¼, and 16 miles per hour. It can be loaded and dumped

Fig. 64.—Truck-wagons with traction units and trailers all running on large pneumatic tires.

quickly, the body dropping forward 90 deg. to a vertical angle for dumping. In general, hauling, dumping, and spreading are accomplished by the driver, since the body is so arranged when it is dumped that the load itself can be bulldozed into a level area.

Truck-wagons.—In recent years an adaptation of the crawler tractor-and-wagon unit has been developed, which consists of a special pneumatic-tired truck and two-wheeled wagon trailer (Fig. 64) whose front end is mounted directly on the rear of the truck. No collective name has been established for this type, but a variety of trade names have been employed, such as: "Trail-car," "Trail-dump," "Speedster," "Trac-Truk," and "Semi-trailer." The designation "truck-wagon" is here employed. The truck unit weighs considerably less than a crawler tractor and is designed so that it carries part of the transported load, which aids in developing sufficient traction.

The truck-wagons range in capacity from 4 to 11 yd. water level, and are capable of speeds up to 18 miles per hour. The equipment has an economical operating range from 500 up to 3,000 ft. and more. At 1,500-ft. average haul, material can be transported for 7 to 10 cts. per cu. yd. Most of the modern truck-wagons are designed for dumping and closing by the driver without slowing down or stopping the unit. The truck-wagons are larger than standard trucks, and this is a real advantage in cutting down the loss of exchange time at the loading point.

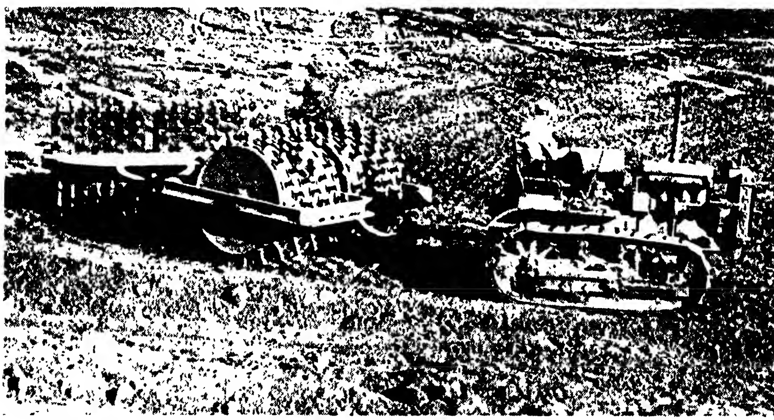


FIG. 65.—Sheeps-foot rollers for compacting earth.

Compactors.—For developing suitable compaction on rolled-fill dams, tractor-drawn sheeps-foot rollers are now almost universally used, as shown in Fig. 65. As compared with the older three-wheel smooth rollers, the sheeps-foot has a tamping action as compared with a rolling action, and this results in a bonding between layers and a density of fill greater than can be obtained with smooth rollers. The great freedom with which tractors can maneuver and haul such rollers over a fill greatly adds to their utility. The standard roller usually consists of two drums about 4 ft. long and 4½ ft. in outside diameter, weighing about 2,500 lb., and exerts a bearing pressure of about 125 lb. per sq. in. of foot area. Further adjustment in weight can be made by filling the roller with water to suit the compaction requirements of the material, thereby developing a unit foot pressure of around 200 lb. per sq. in.

Against core walls or other parts of related structures, and along abutment lines, where it is impossible to work effectively with a large roller, pneumatic tamping hammers have been generally used; more recently the "Delmag Frog" tamper has been developed, which can do a great deal more work and still can be operated by one man. It contains a single-cylinder combustion engine which actuates the Frog into a jumping action, causing it to rise about 9 in. and move forward 9 in. per stroke, and it can make about 50 strokes per minute. The Frog was introduced on San Gabriel Dam in California, where it was found that about 3,000 sq. ft. of area can be compacted per hour of operation.

CHAPTER XV

SPECIAL TYPES OF TRANSPORTING EQUIPMENT

Railroad Trains.—The current trend has been away from locomotives and trains for general hauling of excavated materials around the usual construction job. Expensive roadbeds, limitations in grade, and the constant shifting of track tend to make railroad haulage uneconomical as compared with other types of equipment, except in stabilized situations, such as delivery from a gravel pit, aggregate plant, mixing plant, or quarry, where the distance is long or where both loading and dumping occur at fixed positions. For such fixed or long-distance operations, however, there is no equipment that can handle and transport materials so cheaply as the railroad.

The handling of 50,000,000 tons of gravel for the Fort Peck Dam over a distance of 12.2 miles was obviously a railroad job for which standard-gauge service was used. At Norris Dam the delivery of concrete from mixers to cableway by means of 6-yd. special dump cars, was done by railroad, the hauling distance being from 250 to 750 ft. For such services, the railroad has special advantages of speed and continuity of service. A careful system of dispatching and traffic regulation is essential to best performance. The attention to safety measures is particularly important for railroad work because of the inability to control the equipment under emergency conditions as readily as can be done with smaller individual hauling units.

The size and type of cars to be employed on a job depend on local conditions and the nature of the material. Aside from regular full-sized railroad equipment, standard-gauge (56½ in.) construction cars are available in sizes of 10, 12, 20, 25, 30, 35, and 50 cu. yd. (water-level measurement). They are usually of the side-dumping type with either drop-doors or rising sides. The bottom of the car tips to an angle of 45 to 50 deg. either way. The drop-door dumps farther away from the track as the material slides out and over the door, but this feature requires more

maintenance than the rising sides. The dumping is usually done through air controls, which may be located at the locomotive or on the cars where a separate operator can control the dumping. A 30-yd. air-dump standard-gauge car costs about $4,600. A similar car of a 20-yd. capacity costs about $3,600, and a 12-yd. car, about $2,200.

In the narrow-gauge range, the 3-, 4-, and 5-yd. single-truck and the 8-yd. double-truck sizes run on 36-in. gauge. There is also the 2-yd. size running on 30-in. gauge and a 1½-yd. size running on 24-in. gauge. The dumping operation is usually manual for these sizes.

Selection of Locomotives.—Locomotives are rated in terms of their actual weight, because for a given train of loaded cars, a locomotive of certain weight is required in order to develop enough friction on the rails to get the train in motion. This friction is called "tractive effort" and is equal to the weight of the locomotive on the drive wheels multiplied by the coefficient of friction, which runs from 0.18 to 0.25 for steel tires running on normal dry clean rails. The maximum tractive effort occurs when the driving wheels slip, and the drawbar pull required on a given train to set it in motion must, of necessity, be less than the maximum tractive effort of the locomotive—otherwise the wheels on the driver will slip. The condition of rails and railbed has an important effect on locomotive performance, and grades and curves should be kept at a minimum. For steep grades, the power of the standard type of locomotive is insufficient, and a special geared type of heavy-duty locomotive is employed.

The following process is a step-by-step method of selecting a locomotive:

First, the production requirements are determined, together with the number of cars required per train, the weight of material hauled, and the weight of the cars. The drawbar pull required to move the entire system forward is determined in the following manner:

The drawbar pull necessary to start a train and maintain it in motion on straight, level track is 20 lb. per ton of train weight, exclusive of locomotive weight. The drawbar pull necessary to overcome gravity on grade is 20 lb. per ton of train weight exclusive of locomotive weight per each 1 per cent grade or

fraction thereof. The drawbar pull necessary to negotiate a curve is 0.8 lb. per ton of train weight inclusive of locomotive weight for each degree of track curvature. By using the three foregoing principles in the proper combinations and adding up the total drawbar pull, the required weight of locomotive, in tons, is obtained by multiplying the drawbar pull in tons, by 4. With the foregoing information as a start toward selecting the required size of locomotive, it is now necessary to analyze the speed consideration to fit the job, also the rate of acceleration, the need for high starting power, and the distance and rate of travel in both directions. Table 28 gives representative information on standard construction-type locomotives.

Special Trailer Truck.—The equivalent of a railroad train on pneumatic tires for long-distance hauling on roads was announced early in 1939. The unit consists of a traction chassis weighing 36,000 lb. and powered by two six cylinder 5¾- by 6-in. engines operating on butane fuel, pulling two trailer units with a capacity of 80 tons pay load. Designed for mining or logging industries, the loaded unit weighs over 112 tons. Each engine drives a large electric generator which in turn drives a set of 125-hp. motors connected to the main axles. There is no mechanical connection between engines and axles, and speed control is very smooth. The unit has 30 tires and travels at speeds up to 32 miles per hour.

Chambers Bridge.—A special type of transporting unit which was developed on the Mississippi levee construction and later used on the Florida Canal is known as the Chambers Bridge which consists essentially of a central traveling tower, from which two structural steel arms, 175 ft. long, project in opposite directions and develop a 370-ft. runway for a 10-yd. dump car which is electrically controlled from a 150-hp. hoist in the central tower. The bridges are supported by wire ropes running down to the hoist and may be raised or lowered to attain the angle best suited to operating conditions. The entire machine is self-propelling, being mounted on crawler trucks, and can be maneuvered into working position with almost the speed of a large dragline. Its total weight is 278 tons. The car can be dumped anywhere along the arm and makes a complete cycle in about 50 sec. Its average output is about 9 yd. per cycle. It is loaded automatically from a stationary hopper in one end of the bridge,

TABLE 28.—DIESEL LOCOMOTIVE HAULING
(On well-maintained track, easy curves)

Rated locomotive size, tons; max. speed	Load pulled, tons	Level track: Time required, min. to start, haul and stop distances given below: 500 ft.	1,500 ft.	2,500 ft.	Level track: Speed, max. attained, m.p.h.	3 % Adverse grade: Time required, min. to start, haul and stop distances given below: 500 ft.	1,500 ft.	2,500 ft.	3 % Adverse grade: Speed, max. attained, m.p.h.	Max. hauling load: Level track, tons	3 % grade, tons	Speed attainable under these loads, m.p.h.
8 12 m.p.h.	10	0.7	1.7	2.7	12	0.8	1.8	2.7	12.0	200	44	4.0
	30	0.9	1.9	2.8	12	1.2	3.1	5.0	6.0	115	23	9.0
	50	1.0	2.0	3.0	12	Max. load—44 tons				80	14	12.0
10 13 m.p.h.	20	0.8	1.6	2.5	13	0.9	2.0	3.0	11.0	250	55	4.8
	40	0.9	1.8	2.6	13	1.4	3.2	5.1	6.0	170	35	8.0
	60	1.1	2.0	2.8	13	Max. load -55 tons				100	18	13.0
14 13.5 m.p.h.	20	0.7	1.6	2.4	13.5	0.9	1.8	2.7	13.5	350	77	5.3
	50	0.9	1.8	2.6	13.5	1.2	2.6	4.0	8.0	240	50	8.0
	80	1.0	2.2	3.0	13.5	Max. load—77 tons				100	14	13.5
20 15 m.p.h.	20	0.7	1.5	2.2	15	0.8	1.7	2.5	14.0	500	110	4.0
	50	0.8	1.6	2.4	15	1.1	2.3	3.5	10.0	315	64	8.0
	80	0.9	1.8	2.6	15	1.3	3.0	4.6	7.0	185	31	12.0
	110	1.0	2.2	3.2	11.5	1.7	4.6	7.4	4.0	120	15	15.0
30 17 m.p.h.	30	0.7	1.4	2.1	17	0.8	1.6	2.5	14.0	750	165	4.8
	75	0.8	1.5	2.2	17	1.0	2.1	3.2	10.0	490	100	8.0
	120	0.9	1.7	2.4	17	1.4	3.2	5.0	6.0	280	48	12.0
	165	1.0	1.9	2.7	13.6	1.7	4.1	6.5	4.8	120	8	17.0
40 20 m.p.h.	40	0.7	1.4	2.0	20	0.8	1.7	2.6	13.0	1,000	220	3.5
	100	0.9	1.6	2.3	18	1.4	2.9	4.4	7.0	560	110	8.0
	160	1.0	1.8	2.5	16	1.6	4.1	6.5	5.0	340	55	12.0
	220	1.1	2.0	2.9	14	2.1	5.3	8.6	3.5	90	. .	20.0
60 25 m.p.h.	60	0.7	1.5	2.0	23	1.1	2.0	2.6	11.0	1,500	330	3.0
	150	0.9	1.7	2.3	20	1.3	3.3	5.2	6.0	800	155	6.0
	240	1.1	2.0	2.7	16	1.8	4.7	7.5	4.0	400	55	12.0
	330	1.2	2.2	3.0	14	2.3	6.1	9.9	3.0	90	. . .	25.0

Below heavy line, maximum speed not attained.
Below dashed line, insufficient power to haul at maximum speed.

a time-saving feature because the hopper can be loaded while the car is on the move. A standard 5-yd. walking dragline has usually been employed in combination with the bridge as a loading unit. The entire unit, with a crew of 12 men employed on the complete operation, handles an average of 8,000 to 10,000 yd. per day with a maximum of around 14,700 yd. A total of 260,000 yd. can be moved by this machine in one month.

Cableways as Transporting Units.—Sometimes cableway equipment is the best means of doing a job. Occasionally the availability of a special cableway for other purposes permits the equipment to be worked into transporting service to considerable advantage. Such a special application involving the use of 10-yd. rock skips was made at Madden Dam. The service consisted essentially of removing foundation excavation from deep areas where it was difficult to haul with trucks or tractors. Three 10-yd. skips were employed and were successively loaded with a dragline. A loaded skip was hooked to the dumping bridle on the cableway, raised approximately 150 ft., and then transported a distance of about 1,000 ft. to the higher abutment level at either end. This operation ran for more than 2 weeks, and the best performance was 100 skip loads in 8 hr. It was estimated that each load carried approximately 8 yd. of bank measure rock and earth. The average performance ran between 70 and 75 skip loads per 8 hr. The best time cycle for one operation was 3 min. 28 sec.

Tramways.—Figure 66 shows a further example of transporting materials over cables. The aerial tramway is particularly suited to transport materials over mountainous or rough country where the quantity to be handled is sufficiently large to justify the first cost of the installation. On such projects as Madden, Conchas, Pine Canyon, and Pardee dams, tramways were used with considerable success in transporting gravel from pits located 1 or more miles from the dam sites. In the case of the Madden Dam project, more than 600,000 yd. of gravel was transported a distance of 1 mile at the rate of 225 tons of gravel per hour. The conveying speed was 500 ft. per min. and a total of 50 buckets, each with a capacity of 32 cu. ft. was employed. A 100-hp. motor was required to keep the 2-mile circuit of loaded and empty buckets in motion. A special loading terminal is required where the buckets automatically disengage from the traveling

line and come to a stop under a loading chute; here the material is discharged from a storage bin into the buckets after which they are again engaged with the tramway line and carried out over the cable spans. The longest span was 1,826 ft., and the shortest 400 ft. At the discharge end, the buckets passed through a

FIG. 66.—Tramway transporting gravel 1 mile over hilly country.

special discharge terminal where opening, dumping, and reclosing of the buckets occurred automatically without stopping them. The return travel of the buckets was accomplished by changing their direction in traveling halfway around a pulley 16 ft. in diameter. Tramways are not suited for direct loading from excavation equipment. One of the longest tramways is located in Peru and has a length of 30 miles.

Belt Conveyors.—The use of belt conveyors for handling excavations has risen into greater prominence, and the high

quality of belting now obtainable has contributed as much to the increased use of belt conveyors as improvements in rubber tires have added to trucking and hauling service. We shall here discuss only the handling of excavation; a later chapter will discuss conveyors for aggregate plants.

TABLE 29.—CHARACTERISTICS OF BELT CONVEYORS (ANTIFRICTION TYPE)
(For material weighing 100 lb. per cu. ft.—lagged drive pulley)

Belt width, in.	Maximum			Belt plies recommended*		Maximum belt tension,† lb.	Maximum length of flight for heaviest belt, ft. (col. 6) (see note below)			Recommended motor size for cols. 6, 8, 9, 10, hp.
	Speed recommended, ft. per min.	Size piece, in., not over 10 per cent of total	Output full load, cu. yd. per hr.	Sand	Boulders and rock		Horizontal	25-ft. lift	50-ft. lift	
1	2	3	4	5	6	7	8	9	10	11
14	300	3	75	3	4	1,680	1,080	790	510	15
16	300	4	100	3	4	1,920	1,000	680	370	15
18	350	5	150	3	5	2,700	1,180	860	520	25
20	350	6	180	4	5	3,000	1,180	840	500	30
24	400	8	300	4	6	4,320	1,180	810	440	40
30	450	11	525	4	7	6,300	1,230	820	410	75
36	500	14	850	4	8	8,620	1,220	800	370	100
42	550	17	1,250	5	9	11,300	1,210	770	330	150
48	600	20	1,800	5	9	13,000	1,100	640	200	200
54	600	24	2,300	6	11	17,800	1,190	730	270	250
60	600	28	2,800	6	13	23,400	1,300	840	370	325

NOTE: If less than maximum belt plies are used, the lengths and power given should be reduced.

* 32-oz. duck belting with 2,500-lb. per sq. in. rubber cover.

† Allowed at 30 lb. per ply inch belt tension and cover friction pull at 17 lb. per sq. in. Provides a factor of safety of 6. This table for estimating only.

A conveyor layout is, as a rule, a special job and must be designed to fit local conditions. Table 29 gives general performance data and characteristics of large conveyors. Lower speeds than those shown should be used in case of smaller belts or where it is desired to load the belt higher. The usual angles of slope for belt conveyors are 15 deg. for dry sand and for screened gravel, and 18 deg. for unscreened gravel. The shape of the particles has considerable influence on determining slopes as a conveyor should not be so steep as to permit rolling back of the material. Length of a horizontal conveyor flight is gen-

erally limited to around 1,100 ft. when carrying material weighing 100 lb. per cu. ft. This is due to the limits of allowable belt tension. For lighter materials, the length may be greatly increased. Further details regarding belt-conveyor equipment are given in Chap. XXIV.

The most notable recent installation of belt conveyors for large construction projects were at Grand Coulee Dam, Fort Peck tunnels, and the Florida Canal projects. At Grand Coulee, more than 10,000,000 yd. was moved, and this project represents

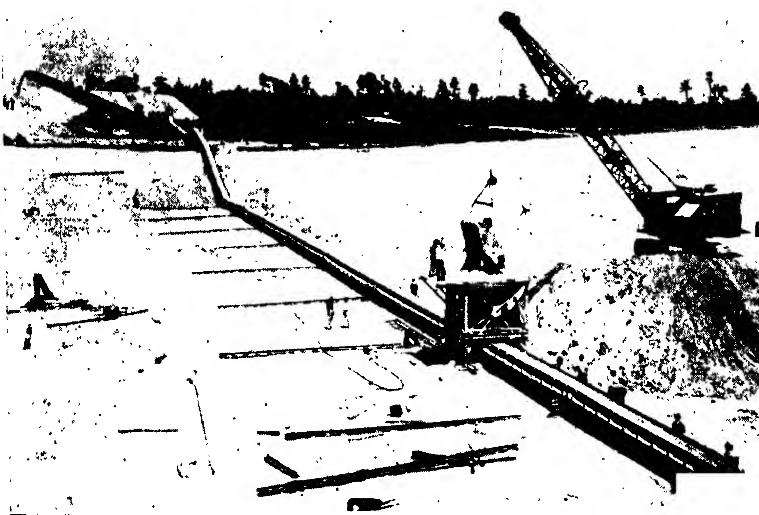


FIG. 67.—Mobile belt-conveyor system for building wide channel.

one of the finest examples of conveyor installations, in which proper recognition was given to all the various elements that go into the design of such a system. It is estimated that over $1,000,000 was spent on the excavation plant on that project. The excavation system consisted of loading by shovels to tractors and wagons, which carried the material to grizzlies (located flush with the ground surface) and over heavy-duty feeders which were depressed below the ground. A bulldozer was used to break down the largest sizes and force them through the grizzly into the feeder. These feeders delivered the material to 42-in. tributary conveyors which carried the earth to a central hub feeder which, in turn, fed the material in a smooth stream to

a 60-in. main conveyor. The total time efficiency of the conveyor system was 95 per cent which shows the remarkable reliability of this class of equipment. The following table gives the main characteristics of the Grand Coulee installation:

Total length of main conveyor:	
Feeders and laterals	6,048 ft.
60-in. main conveyor:	
Number of flights	19
Maximum slope	14 deg.
Length of flights	156 to 415 ft.
Total length	4,648 ft.
Gross lift	626 ft.
Loss of lift in transfers	160 ft.
Speed of travel	620 ft. per min.
Power on each flight	200 hp.
Power on feeders and laterals	1,115 hp.
Power on discharge stacker boom	280 hp.
Total power installation	5,200 hp.
Output:	
Best in 7 hr	17,428 yd.
or	2,540 yd. per hour
Best in 21 hr	50,700 yd.
or	2,420 yd. per hour
Longest steady run	59 hr. 8 min.
Best month	1,120,000 yd.

On the Florida Canal, two sets of conveyors were used and were loaded directly through loading hoppers by draglines. One installation was 800 ft. long, loaded by two 2½-yd. draglines with 50-ft. booms. This unit moved about 12,000 yd. per day or 200,000 yd. per month. The system was mounted on tee rails and could be moved sidewise by pulling with two tractors. A total of 22 men comprised an operating shift. Another installation consisted of a unit 950 ft. long, with 36-in.-wide conveyor fed by one 2½-yd. dragline (Fig. 67). Experience has indicated that more loading capacity could have been used on this job. The dragline made three passes per minute and loaded from 8,000 to 9,000 yd. in 20 hr. In the best month, 170,000 yd. was loaded. The stacking at the discharge end was handled by means of a 100-ft. boom stacker. A crew of 14 men comprised the shift on this unit.

Hydraulic Pumping.—An effective method for moving large quantities of earth and gravel is the system of hydraulic pumping

which was used to a very large extent on the Miami Conservancy District and is fully described in its publications. This process was used as a means of developing a reclassification of the materials as is frequently necessary in the construction of earth dams. As shown in Fig. 68 the earth and gravel were hauled by train into large hog boxes where they were mixed with large quantities of water and pumped through dredge pipe to the site of the dam.

Fig. 68.—Earth and gravel dumped into hog boxes for mixing with water before entering dredge pump and pipe line.

This was a necessary operation because in the original state the material was a rather uniform mixture of gravel, sand, and some earth. This material was too porous to be used in a dam and the purpose of the hydraulic operation was so to combine the material with water that, at the discharge end, it would leave the gravel at the outer faces of the dam and grade uniformly toward the center of the dam where the finest particles would accumulate and settle to form an impervious core. On the Miami work, 15-in. pumps were used and more than 7,000,000 cu. yd. of material was pumped into the five dams. A run of 300 to 400 yd.

per hr. was frequently obtained, and a total of 91,500 yd. was put through a single pump in 1 month. Production rarely came up to the maximum dredge capacity of 600 yd. per hr. owing to the limited capacity of the hauling and sluicing system.

A more recent installation of the same type of operation occurred at Quabbin Dike, Mass., where 2,100,000 yd. was moved at the rate of about 8,000 to 10,000 yd. per day and 50,000 per week. This project is of special interest because the specifications provided for three different methods of moving the material from bank to dam; one by sluicing from the hillside directly into a pit where a dredge pump would transfer and pump it to the dam; the second, loading the material into trucks, the trucks dumping into hog boxes, and the material sluicing out of these hog boxes and flowing by gravity to the dam; third, the material loaded into railroad cars, dumped into hog boxes, and delivered to the dam by a dredge pump or by gravity flow. Fortunately, the ingenuity of the contractor was permitted to introduce a fourth and more efficient method which consisted of tractor and truck deliveries from the bank to a dredge pump setup, with the material, however, going through a mechanical feeder and revolving grizzly into a concrete sluiceway to provide a constant feed to the pump. This was probably one of the most important features which led to the successful execution of this job. About 500 yd. of solids was pumped per hour, the solids running 13 to 15 per cent. A 20-in. line, 2,500 ft. long, delivered the material to the dam. The pump was rated at 185-ft. maximum head with a 1,000-hp. motor driving it at 392 r.p.m.

Semihydraulic Method of Dam Construction.—On El Capitan Dam 1,700,000 cu. yd. of earth was brought in by trucks and dumped along the upstream and downstream edges, and segregation and redepositing of materials were obtained by sluicing the material down and letting the fine material run into the core. The trucks had about a 1½-mile haul, and the material was washed down by 2-in. and 3-in. nozzles, operating at pressures of 50 to 60 lb. per sq. in. and receiving water through 8-in. pipes. The pumps were mounted on rafts floating on the pool in the zone of the core and delivered from 3 to 4 cu. ft. per sec. of water. Four such units placed a total of 8,000 to 12,000 yd. per day of two shifts, the water in general circulating and being used over and over. About 150 gal. of water was used per cubic yard of fill.

Dredge Pipe.—Since dredge pipe lines are essentially a transporting medium as distinct from the dredge, which was discussed in Chap. XIII, a special discussion is here presented, although the pipe line and the dredge comprise a single operating unit.

Certain principles should be observed in laying out a pipe line: first, the floating line should be as short and as straight as possible; second, the land layout should as far as possible be on accurate alignment and evenly graded. Friction losses in the lines depend a great deal on the nature of the material. The highest losses occur in handling rough and sharp heavy gravel; the losses decrease where the sand content is greater; the presence of fine clay has a substantial effect in reducing losses because of its lubricating effect. Mud and silt may run up to 20 per cent of solids, whereas sand and gravel usually run around 10 per cent in solids. The following table gives representative friction losses in pipe lines handling sand and gravel:

TABLE 30.—FRICTION LOSS IN FEET PER 100 FT. OF DREDGE PIPE CARRYING WATER WITH SAND AND GRAVEL

Velocity, feet per second	Pipe diameter, inches			
	10	12	16	20
10	6 to 9 ft.	5 to 7 ft.	4 to 6 ft.	3 to 6 ft.
12	10 to 13 ft.	7 to 10 ft.	6 to 8 ft.	4 to 8 ft.
14	13 to 16 ft.	10 to 13 ft.	7 to 10 ft.	6 to 10 ft.

About 20 ft. of head is lost on the suction side.

For large operations, floating line pipe is generally made in 45- to 48-ft. lengths, which permits shipping the pipe in 50-ft. cars. On the Great Lakes and in certain other cases, lengths of 100 ft. have occasionally been employed because of their greater freedom from difficulty due to wave action. The length of shore pipe for dredges between 20 and 30 in. is between 15 and 16 ft. which allows easy handling. Dredge pipe is made of special composition steel with 0.30 to 0.40 carbon and with electric-welded seams. The thickness of floating pipe runs from $\frac{5}{16}$ to $\frac{7}{8}$ in., and shore pipe is usually $\frac{1}{8}$ to $\frac{5}{16}$ in. for smaller dredges.

For long-distance lines, it is necessary to install boosters, and these are usually pump units of the same type and characteristics as those located in the dredge itself. It is particularly important that all boosters and pumps run at the same speed. Since some pressure, around 5 or 6 lb. per sq. in., should be maintained at the entrance side of the booster, its proper location in the line is equally important.

Light draglines offer an efficient means for the handling of shore pipe and are most satisfactory for casting up levees or leveling off high spots on the fills.

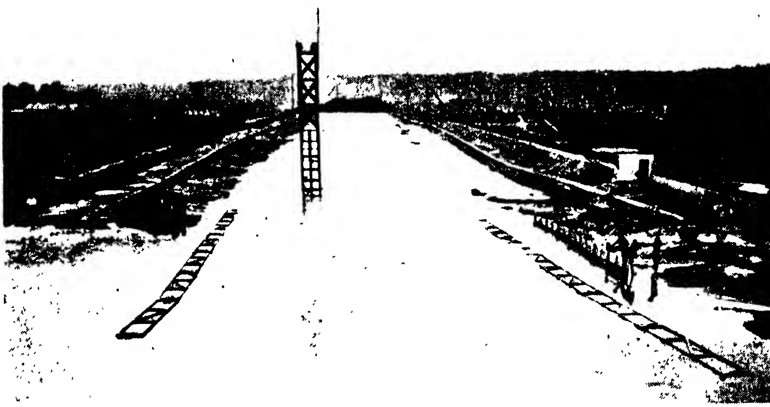


FIG. 69.—Discharge end of dredge line builds up disposal at left while dragline raises retaining dike at right.

Representative performance with a medium-sized dredge is found at Pickwick Landing Dam (Fig. 69), where a 16-in. dredge with 800-hp. motor pumped a distance of 1,500 to 1,800 ft. and the booster pump extended this distance to about 3,700 ft. The material ran about 8 to 10 per cent solids and contained a large amount of gravel, with smaller size material ranging down to clay. The shrinkage in moving the material from bank into the hydraulic-fill dam amounted to 12 per cent, and a total of 150,000 to 175,000 cu. yd. was placed per month. About 2.5 to 3.5 kw.-hr. of energy was used per cubic yard.

The most notable installation of dredging was at Fort Peck Dam where the distance of transportation was 17,000 ft. and the vertical rise 240 ft. in elevation. Five 28-in. pumps were used in series, and 6,250 hp. were used on each pipe line. About

1,200 to 1,900 cu. yd. per hour was moved or a total of 3,300,000 yd. per month by four such dredge systems. The biggest day was 189,000 yd. on July 3, 1936, by the four systems. About 5.38 kw.-hr. was used per cubic yard of material moved, which was sand and silt, running about 13.2 per cent solids. The velocities have been around 20 ft. per sec., and the floating line loss runs from 4 to 7 ft. per hundred feet of length, whereas the land-line loss runs from 3 to 5 ft. per hundred feet of length. This low line loss was obtained through exceptionally accurate alignment.

Barges.—For certain special conditions of service on rivers, barges may prove most effective, as in the case at Wheeler Dam where gravel was delivered from a ladder dredge a distance of 25 miles upstream to the dam. Special deck barges were used for this purpose, which permitted the water in the materials to drain off in transit. For maximum economy it is desirable to have large barges with capacities of 400 to 600 tons per barge to reduce the cleanup cost in unloading. In certain special cases, self-unloading barges of the mechanical or the tip-over types are advantageous as on deep-sea dumping of spoil material.

Summary.—Transporting equipment and conditions under which it operates represent such a large number of varied conditions, that, as one manufacturer put it, "Knowledge of new equipment and the ability thoroughly to analyze jobs is absolutely necessary in order to keep abreast of the times. The old-time construction man is fast being replaced by the construction engineer, who, by virtue of his training, is capable of making a proper job analysis." This might be reworded by saying that the old-time construction man must learn to utilize the ability and assistance of equipment experts in order to keep from being displaced.

CHAPTER XVI

COMPRESSED-AIR SYSTEMS

Compressor Plant.—The compressed-air plant for a large job usually does not receive sufficient advance planning in proportion to its importance. A properly designed plant, in comparison with one that "just grows up," will be more efficient, will improve the performance of air tools, and will result in less tool repairs and power consumption.

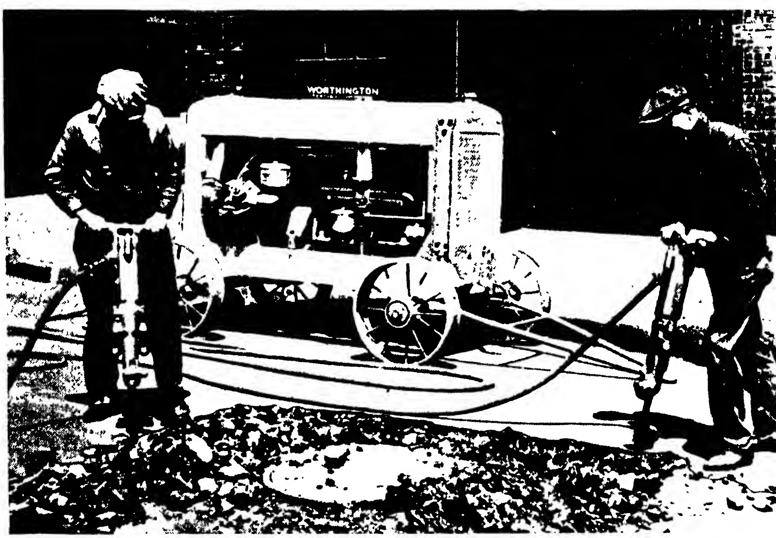


FIG. 70.—Portable air compressor and paving breakers.

In selecting large compressors for a central plant the variation in load from month to month dictates flexibility, and on a large construction job it is usually better, for example, to have two 3,000 cu. ft. per min. compressors in place of one 6,000 cu. ft. per min. compressor, in spite of some extra cost in foundation and building. With the smaller machines it is possible to build up the air plant as the demand rises, and in cases of a machine break-

down the job will not be completely stopped. Smaller machines are more portable and can be moved off sooner as the demand on the job grows less in the later stages.

Portable compressors (Fig. 70), either gasoline or Diesel driven, are available up to about 900 cu. ft. per min., in single- or two-stage types. Stationary compressors (Fig. 71) in standard capacities up to 7,500 cu. ft. per min. are either gasoline, Diesel, or electric driven in one- or two-stage types. In recent years

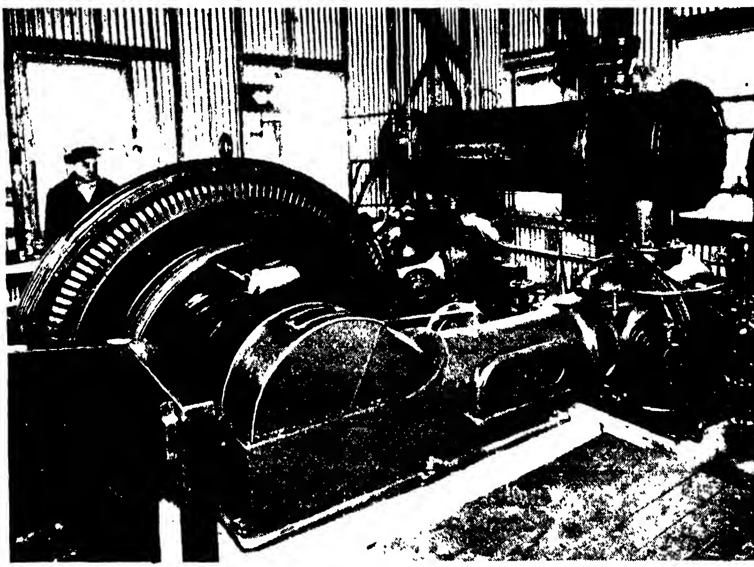


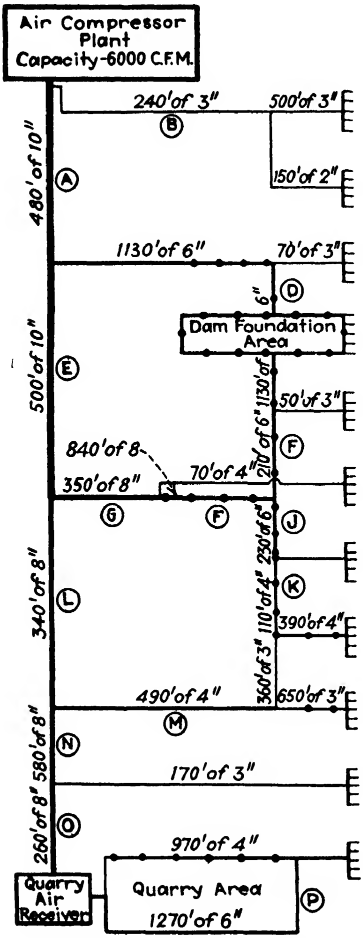
FIG. 71.—Stationary air compressor, two-stage type with intercooler.

the development of rotary compressors has been very rapid, even in the large sizes, and deserves consideration especially where compactness is of importance.

In determining the air requirements for a job an estimate is made of the consumption of all tools required, on the basis of their expected staggered operation, to arrive at a probable peak demand. Table 31 and Fig. 72 present such an estimate and a layout for a project showing the use of air and the necessary piping system.

Rating.—Air compressors are rated by piston displacement in cubic feet per minute, which is the volume swept by the piston in one minute. The actual output of a compressor is less than

the piston displacement because of air left behind in the clearance spaces and because of leakage. For example, the actual output of a compressor rated at 6,000 cu. ft. per min. is about 5,290. The output of a compressor is the volume of air actually com-



SERVICE	Max. Air Demand C.F.M.
Carpenter and machine shop	600
Gas service station	300
Cableway head tower	600
Drilling, grouting cleanup and misc.	3000
Cableway tail tower	600
Cement silo	600
Mixing plant service tap	300
Rim grouting area feeder	900
Aggregate screening and storage plant	600
Aggregate crusher	600
Drilling blast holes	1500

Max. Line Discharge At	C.F.M.
A	6000
B	600
C	1800
D	1800
E	4800
F	1800
G	3000
H	2400
J	1500
K	900
L	3000
M	1200
N	2400
O	2100
P	1500

Lines provided with service taps.
Looping lines are designed to carry the full load from either side to insure service if the loop is broken.

FIG. 72.—Compressed-air distribution system for large construction job.

pressed and delivered, measured at the intake pressure and temperature as free air, and not as compressed air. For discharge pressures of 70 lb. and above, two-stage compressors are generally preferable because of their lower power require-

TABLE 31.—PNEUMATIC EQUIPMENT
(Air consumption and estimate of air requirements for Norris Dam)

	Cu. ft. of air per min. per machine required at approximately 80 lb. pressure	Number of units		Total air required, cu. ft. per min. (diversity allowed)
		Average on job	Working	
Excavating Equipment:				
Wagon drills—drifters	230	16	8	1,380
Jackhammers	91	30	20	1,183
Clay diggers	75	2	2	150
Drill sharpeners	160	2	2	320
Oil furnace	75	2	2	150
Shank grinders	47	2	1	47
Blow guns, blast hole	147	2	2	200
				3,430 Diversified—3,000
Cement plant:				
Blowing cone—silo	186	1	1	186
Cement pumps	160	2	1	160
Grout pumps	220	4	3	660
Blow guns—concrete cleanup	82	4	2	164
Concrete surfacer	50	2	2	100
				1,270 Diversified—1,200
Hoists, pumps, motors:				
Motor—grout mixer	100	6	3	300
Pumps	100	3	2	200
Hoists	160	18	10	800
				1,300 Diversified—1,000
Miscellaneous tools:				
Paving breaker	55	1	1	55
Chipping hammer	25	9	6	125
Riveting hammer	42	12	10	336
Holder-on (bucking up)	25	4	4	100
Air wrench	75	2	2	150
Close-quarter drill	75	6	4	225
Woodborer	50	7	5	200
Grinder	50	2	2	100
				1,291 Diversified—1,000
Blowing out lines	200	..	..	200 Diversified— 200
Total	...	..	..	6,400 Diversified—5,000
Line loss	...	..	..	500
Total capacity required	...	..	..	5,500

ment and reduced operating temperatures. For compressor capacities of 1,200 cu. ft. per min. and larger, a direct-connected synchronous motor with 80 per cent leading power factor for power-factor correction is usually employed.

Cooling.—Water-cooled intercoolers are required between stages of two-stage compressors to reduce the temperature and volume of the air compressed by the low-pressure cylinders This volume reduction increases the amount of air entering and, therefore, delivered by, the high-pressure cylinder, and the temperature reduction condenses and removes moisture and improves lubrication. Compressing air to 100 lb. per sq. in. without intercooling or by single-stage compression would result in an air temperature of about 485°F.

Aftercoolers perform a function similar to intercoolers in reducing the temperature of air and in condensing moisture and oil after the air has left the final stage of compression. Wet

TABLE 32.—OUTPUT AND COST OF PORTABLE AND STATIONARY AIR COMPRESSORS, FULLY EQUIPPED

Air Output, Cu. Ft. per Min.	Cost
PORTABLE COMPRESSORS (Gasoline or Diesel)	
100	$1,750
200	3,350
300	4,150
STATIONARY COMPRESSORS (Electric)	
1,000	$ 8,000
2,000	13,000
3,000	17,750
4,000	22,750
5,000	28,500

air is detrimental to pneumatic tools, as it washes away the lubricants, interferes with pneumatic handling of cement, and is subject to freezing in valves, ports, and pipe lines. An aftercooler also reduces the pressure loss in distribution lines due to radiation, cooling, and contraction of the air in the lines.

An air receiver for equalizing compressor-discharge pulsation should be placed outside and near the compressor house. The receiver also serves as a condensing chamber for the removal of water and oil vapors. Its volume in cubic feet should be

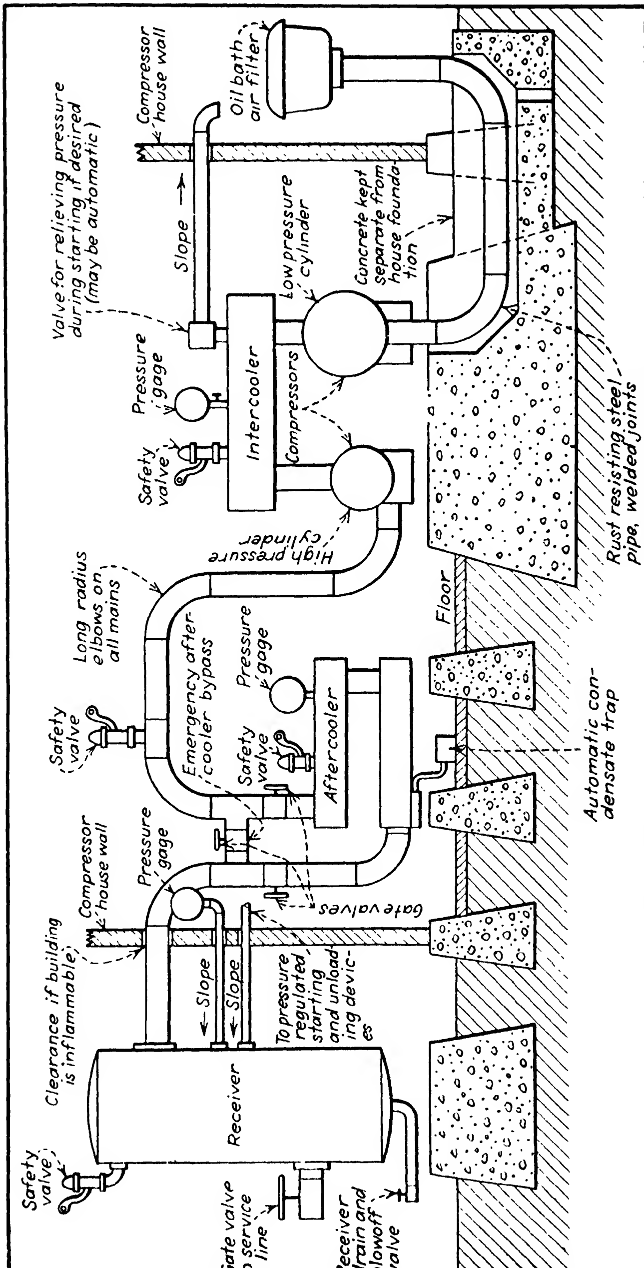


FIG. 73.—Diagrammatic layout of stationary air-compressor system.

from one-sixth to one-tenth times the cubic-foot-per-minute displacement of the compressor, the multiplier decreasing as the compressor displacement increases. Figure 73 shows diagrammatically the features of a stationary air-compressor setting.

Pipe Sizes.—Pipe sizes for mains and branches should be ample and with a minimum of angles and turns, to keep down pressure losses, which result in a greatly reduced output of air tools and equipment. In selecting the size of pipe for main lines the possibility of a future increase in length, or an increase in air requirements, should be kept in mind. Pressure losses per 1,000 ft. of straight pipe at 100 lb. air pressure are given in the accompanying table.

PRESSURE LOSS PER 1,000 FT. OF PIPE LINE

Diam. of pipe, in.	Quantity of air cu. ft. per min.	Pressure loss, lb. per sq. in.
3	1,000	9.3
4	1,000	2.2
4½	3,000	10.9
5	3,000	6.0
6	3,000	2.3

The same principles, of course, apply also to hose. A 50-ft. hose operating at a pressure of 80 lb. per sq. in. and carrying 100 cu. ft. per min. of free air will have the following losses:

PRESSURE LOSS IN 50-FT. HOSE LINE

Diameter of Hose, In.	Pressure Loss, Lb. per Sq. In.
¾	5.8
1	1.4
1¼	0.4

All bends in main air lines should be of long radius. Welded 45- or 90-deg. sharp angles should never be permitted. Where it is necessary to use elbows in the intake line they should be of long radius. A sharp intake elbow greatly reduces the efficiency of the compressor, since it is impossible to carry the air to the cylinder at the required rate properly to fill it.

Reheaters, placed as close as possible to the points of air use, are sometimes useful during cold weather. Reheating the air to 250°F. increases the volume of air about 30 per cent, with a

corresponding increase in working pressure. Reheating dries up the air, reduces the freezing nuisance, and raises the operating efficiency of the tools.

Leaks.—One of the most important problems on a job is the stopping of costly air leaks. Such leaks may be in either loose joints in the pipe lines or excessively worn pneumatic tools, with consequent low efficiency of operation. The following data show the loss per month of compressed air, assuming it to be valued at 10 cts. per 1,000 cu. ft.

AMOUNT AND COST OF AIR LOSSES

Size of opening in.	Cu. ft. wasted per month, 100 lb. pressure	Cost of waste per month at 10 cts. per 1,000 cu. ft.
3/8	10,000,000	$1,000
1/4	4,500,000	450
1/8	1,100,000	110

When one stops to realize that a 3/8-in. opening means a loss of $1,000 per month it is easy to understand that on a large job it would pay to keep a man employed just on checking up air leaks and installing suitable gauges and metering devices to check air consumption at various points and make corrections wherever necessary.

CHAPTER XVII

DRILLING AND BLASTING

Rock Drills.—Drills may generally be divided into two main groups: (1) Percussion drills, which include jackhammers, wagon drills, and well drills; and (2) abrasion drills, which include diamond and shot core drills. The selection of the most suitable type of drill depends, first of all, on the purpose of the holes, and second, on the kind of rock to be drilled. Table 33, on drilling costs and performance, gives some relative comparisons for various types and sizes of drills, and, although based on certain actual experiences, the extreme variations in rocks and other conditions prevent the data from being applied in a general way. Drill performance is affected by size, depth, and spacing of hole; type of terrain; character of overburden; hardness of rock; prevalence of seams and cavities; amount of ground water; conditions of equipment; efficiency of operators; and type and quality of supervision.

Percussion Drills.—The percussion drills include two main types: the hammer drill and the piston drill. In hammer drills a blow is transmitted to a rotating drill rod loosely held in a chuck by a reciprocating piston driven by compressed air. The drill rod is usually hollow for blowing air or water through the rod to clear the hole of cuttings.

Piston Drills.—In the piston drill the drill rod is securely fastened to the piston and travels the full length of the piston stroke. Piston drills are now almost obsolete.

Hammer Drills.—*Jackhammers.*—Jackhammers, sometimes called "sinkers," are unmounted, portable, hand-operated hammer-type drills (Fig. 70), mostly used in drilling vertical holes. The machines vary in size from 25 to 85 lb. in weight and are best adapted to shallow work up to 10 ft. of depth and for secondary blast holes. The tripod drill is similar to a jackhammer, except that it is mounted on a tripod with legs weighted to provide sufficient stability. Tripods are usually very low

TABLE 33.—ROCK-DRILLING COSTS AND PERFORMANCE

Size of hole, in.	Class of rock	Jackhammer		Wagon drill		Diamond core		Shot-drill core	
		Drilling, rate ft. per hr.	Cost per hr.	Drilling rate, ft. per hr.	Cost per hr.	Drilling rate, ft. per hr.	Cost per hr.	Drilling rate, ft. per hr.	Cost per hr.
				Small holes					
1¾ (core 1⅛)	Soft to medium	10 to 20	$1.35	25 to 35	$3.00	3 to 7	$4.40		
	Hard	5 to 10		20 to 25	.....	2 to 4	4.60		
2⅜ (core 1⅝)	Soft to medium	8 to 15	1.45	25 to 30	3.00				
	Hard	3 to 8		15 to 25					
3 (core 2⅛)	Soft to medium	....		10 to 15	3.25	2 to 5	5.40	1 to 3	$3.10
	Hard	....		5 to 10	.....	1 to 3	5.60	½ to 1¼	3.20
4 (core 3)	Soft to medium	....		5 to 10	3.50	.....	.....	1 to 2	
	Hard	....		3 to 5					
				Large holes					
6 or 5½ with core 4¾	Soft to medium	....				3 to 6	$2.50	¾ to 2½	$3.10
	Hard	....				1 to 3	2.75	½ to ¾	3.20
12	Soft to medium								
	Hard	....				1 to 4			
36	Soft to medium	....				.....	.....	½ to 1	4.50
	Hard	....				.....	.....	¼ to ½	4.60

NOTE: Soft to medium rock: varies from shale, soft limestone to siliceous limestone and dolomite. Hard rock includes trap, granite, quartz, chert, graywacke and quartzite. Drilling rates and costs shown are per shift or gross operating hour. All delays are included, such as for moving, repairs, hung steel, low water or air pressure, blowing holes, removing cores, etc. Operating costs include all direct drilling charges covering operating labor, repairs, sharpening, bits, tools and supplies, compressed air, power, pipe casing, equipment depreciation, etc. No charges are included for general overhead and superintendence or insurance.

and require drill changes every 3 ft. They are not much in use except on very hard quarry rock.

Stopehammers are a modification of a jackhammer, with a thrust end to hold the drill against the work and are usually

used for "up" holes. The feeding may be automatic or by hand.

Drifters.—Drifter drills are mounted tools for drilling "up," "down," or "side" holes. Wagon drills and tunneling drills are usually called drifters. They vary in weight from 75 to 225 lb. and are usually operated by a two-man crew. For horizontal or "up" drilling, the feed is usually by means of a

FIG. 74.—Wagon drills on hard rock excavation for dam foundation.

hand or mechanically operated screw or a pneumatic or hydraulic pressure piston. When drilling "down" holes, as with a wagon drill, the weight of the drifter provides the necessary feed.

Wagon Drills.—Wagon drills are best suited for quarry and foundation work with holes up to 30 or 40 ft. They may be arranged to drill in any direction below the horizontal and have an automatic feed, usually sufficient to permit 10-ft. depth for rod changes (Fig. 74).

At Chickamauga Dam, on the Tennessee River, wagon drills with jumbo detachable bits, 4½ in. in diameter, were used on 40-ft. blast holes and averaged about 8 ft. per gross hour. Wagon drills for shallow drilling on quarry and similar installations will lower the drilling costs over those of churn drills because of the increased drilling speed.

At Wheeler Dam, wagon drills were mounted on parallel tracks with wheels removed and skidded along in groups up to five for line-drilling work on holes of 10 to 12 ft. in depth. At greater depths, it is difficult to obtain parallel holes.

Well or Churn Drills.—Well or churn drills are of the reciprocating percussion type and are used for large blast holes from 3 to 8 in. or more in diameter. The bit is attached to a heavy

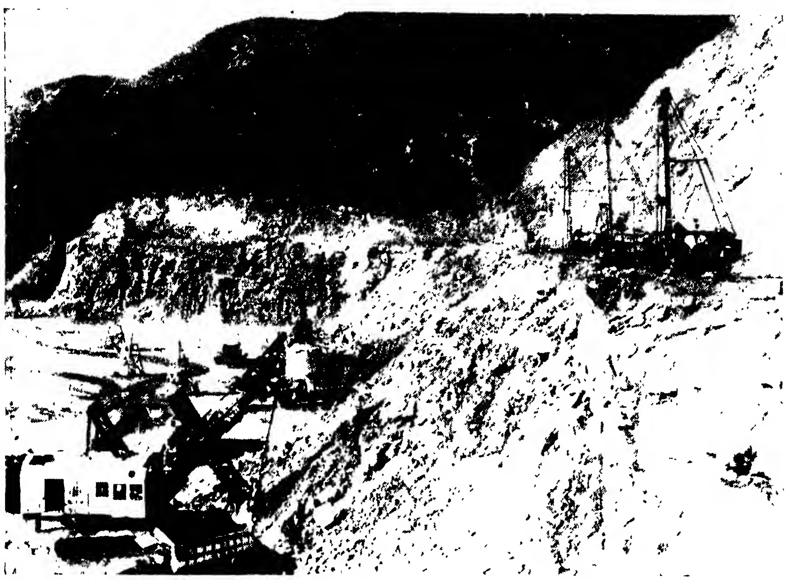


Fig. 75.—Well drills for deep holes on large quarry operation.

bar lifted by a line hoist and dropped into the hole, producing chipping and crushing by the weight of the blow. The loose material is bailed out or washed out. Well drills are ordinarily used on very hard drilling, especially for quarry blasting (see Fig. 75), and can drill down hundreds of feet. They are operated either by steam or gasoline engine or electric motor.

Drilling progress is dependent largely on the weight of the drill tools, and for this reason a hole less than 5 in. in diameter is seldom practical. In fact, holes 6 and 8 in. in diameter can be drilled about as rapidly as a 5-in. hole, with relatively less wear on bits and equipment. A 6-in. hole can be driven through limestone at rates of 3 to 6 ft. per hr., and through traprock or granite at rates of 12 to 20 in. per hr.

Abrasion Drills. *Diamond Drills.*—Diamond and shot core drills have their greatest value in exploration drilling where cores are desired to give the necessary information regarding rock structure (see Fig. 76). Diamond drill bits run in standard sizes up to 3 in., providing a core of 2⅛ in. Above this size, the

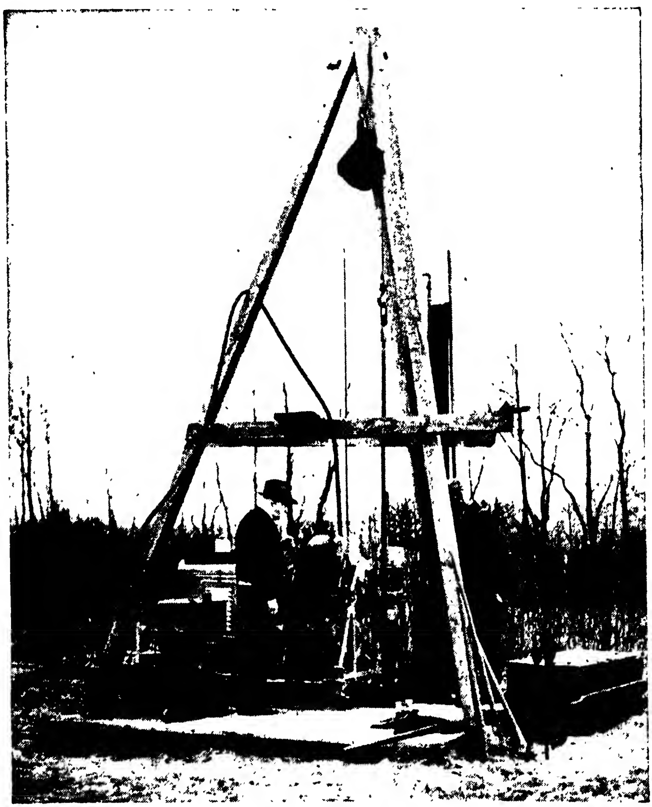


Fig. 76.—Diamond core drill for foundation exploration.

investment in abrasives becomes so large as to preclude the use of this equipment, and shot core drills are generally used.

In a sound rock which dril s well a 1⅞-in. hole with a 1⅛-in. core may give good core recovery. In softer broken rock even the larger sized bits will have difficulty in recovering most of the core. Diamond drills are far superior to shot drills in seamy work. They can drill to a depth of 1,000 ft. or more and operate with core barrels 2 to 10 ft. long. Frequently bortz is used as a

cutting medium in softer rock, although some drillers express a preference for diamonds, claiming that in all cases the longer life more than offsets the higher cost. The main advantage in the use of bortz is the lower investment in case a drill bit is lost.

Black diamonds cost about $40 per carat and require 7 to 8 stones of about 2 carats each for a 1½-in. hole. The diamond bits cost about $600. Bortz bits usually require 35 to 40 stones, sized from 2 to 7 stones per carat, and cost about $7.50 per carat, or $66 per bit. Bortz is sharper and harder than black diamond but less tough and less durable. In hard graywacke at Hiwassee Dam, containing 60 per cent silica, a bortz bit drilled from 40 to 80 ft. per bit. Diamonds or bortz are usually set by hand, although a recent process of casting the metal for the bit into a basket containing the stones in their desired distribution has resulted in substantial reduction of bit cost.

Shot Drills.—For core holes of 3 in. and larger, shot core drills are used with chilled steel shot as the abrasive material. The shot breaks under the bit, and the resulting sharp angular particles are the cutting medium for breaking and grinding the rock under the bit. Although drilling speeds are slower in comparison with diamond-drill holes, the lower bit and abrasive cost are a substantial advantage. There is more core loss in the smaller shot-drill sizes, which makes the lower limit for this equipment about 3½ in. It has been found recently that a 5½ or 6-in. hole can be drilled about as fast as a 3-in. hole. A 5-in. shot-drill hole can be carried to a depth of about 2,500 ft., and a 12-in. hole to a depth of 600 ft. Shot drilling is particularly expensive in cavernous or seamed rock, because it is difficult to hold the shot.

Shot core drills are driven by steam, air, gasoline, or electricity and run in sizes from 1½ to 72 in. Large-diameter cores up to 6 ft. may be driven by modern machines to a depth of 100 ft. The 4-ft. core can be run to a depth of about 200 ft. For these machines about 50-hp. motors are used. They have been used particularly for exploring foundations of dams because they make possible a visual inspection of the formation by lowering the observer into the hole (see Fig. 77).

Although diamond drills are capable of drilling at almost any angle, shot drills are limited to a maximum angle of 45 deg.

downward. Above this angle, the shot lies in the lower side of the hole and may run away.

Special Auger.—For soft rock a special auger was developed and used on several jobs, notably at Fort Peck Dam for drilling 467 shafts 5 ft. in diameter and 30 to 40 ft. through shale. This auger consisted of a 50-ft. drive shaft, turned by a 40-hp. motor and suspended from a derrick. It was equipped with a 5-ft.-diameter cutter pan with special cutter teeth, and after each foot of penetration the assembly was lifted out of the hole to dump the cuttings. Drilling was at the rate of 5 ft. per hr.

FIG. 77.—Shot core drill and 36-in. diameter core.

Drill Rods and Bits.—Drill rods for hammer-type drills come in standard diameters, of 7/8 to 1 1/2 in. and in standard lengths up to 30 ft., with special lengths at times running to 40 and 60 ft. Rods are either hollow with round or hexagonal sections, or solids, with auger, octagonal, quarter-octagon, or cruciform sections. Owing to the wear on the bit gauge, it is general practice to decrease the gauge at regular intervals as the hole increases in depth. In limestone and dolomite this change made for each 10 ft. of depth usually amounts to 1/8-in. gauge. A hole of 1 3/4 in. diameter is about the smallest that can be satisfactorily drilled to appreciable depths.

Drill bits are of either the detachable or forged type and of the following standard shapes:

1. Chisel bits for very hard rocks.
2. Fishtail bits for very soft rocks.
3. Four-point cross bits for medium hard, powdery rock, such as limestone and dolomite. These bits are also used for many hard rocks and are generally considered the "standard" or conventional type of bit.
4. Six-point cross bits for very soft rock or extremely hard but very brittle rock.

Standard bit gauges vary from $1\frac{1}{2}$ to $3\frac{1}{4}$ in. by $\frac{1}{8}$ in. Special detachable bits of $3\frac{1}{2}$ to $4\frac{1}{4}$ in. are also available.

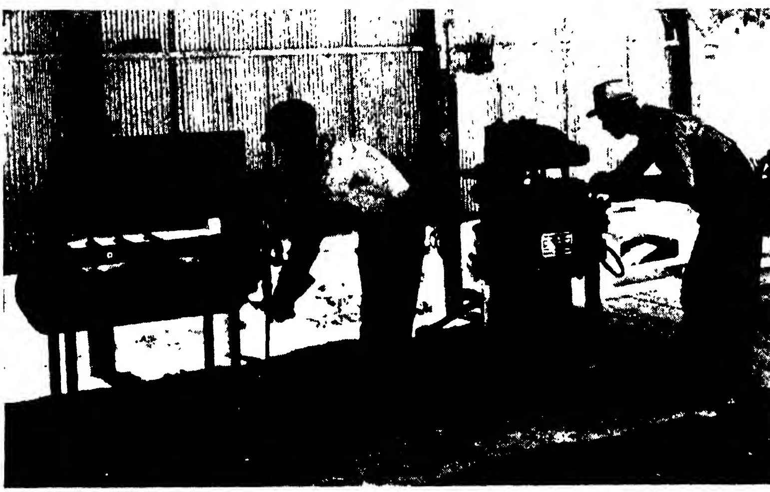


FIG. 78.—Oil-burning forge and drill sharpener for forging bits on drill steel.

One of the most important elements in sharpening bits is the proper heat treatment of the steel to overcome brittleness and fatigue. The rods are subjected to very high stresses, and improper sharpening and heat treatment result in quick failure. When forging the bits or shanks the rods are now almost universally heated in oil furnaces, some of them equipped with automatic control of temperature. A further automatic machine is obtainable for quenching the rods in oil or water in order to obtain a uniform temper. A standard drill sharpening shop (Fig. 78) consists of forges, sharpeners, shank and bit punches, quenching outfit, a grinder, and a shank grinder to square up the ends of rods.

Detachable Bits.—The use of detachable bits (Fig. 79) in place of forged bits is growing rapidly, particularly on work where the handling of drill steel to and from the sharpening shop is an appreciable item. In general, detachable bits have a better metallurgical composition and temper than is obtainable in the

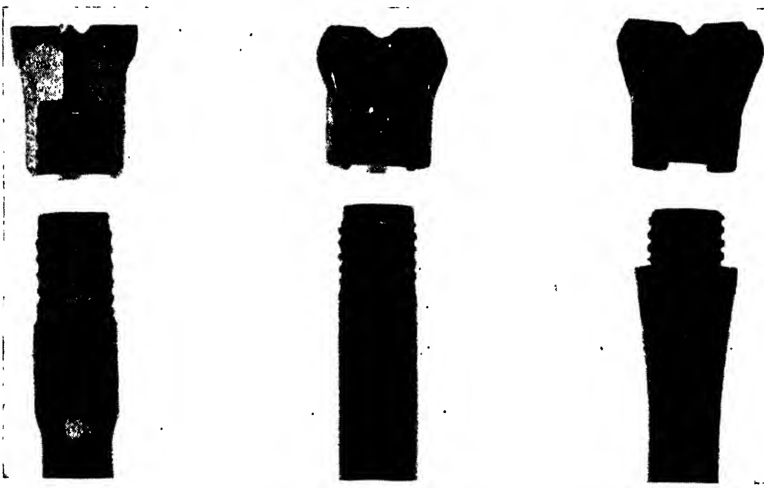


Fig. 79.—Three types of detachable drill bits.

field with forged bits. A comprehensive test on various types of detachable bits and forged bits was made on the Norris Dam quarry over a period of 4 months. The accompanying table describes some of the more general results from these tests and indicates a somewhat lower drilling cost with detachable bits on this quarry:

Results of Drill-bit Tests

	Detachable bits	Forged bits
Linear feet drilled per cubic yard of rock	0.599	0.848
Pounds of rod metal consumed per yard	0.06	0.051
Pounds of rod metal consumed per 1,000 feet of drilling	100.9	60.1
Drilling rate, feet per hour	32.80	28.26
Drilling, feet per fresh point	11.63	10.32
Total cost per foot of drilling (operation, shop, nipping, and material costs), cents	11.79	12.25

Blasting.—A variety of explosives is available to meet particular requirements with respect to velocity of explosion, strength of blow, intensity of fumes, inflammability, and resistance to water and cold. The nature of the blasting requirements and layout of holes must be related to the proper selection of explosives. A slow, confined explosion produces an even blow; fast explosions give a shattering blow.

An essential part of a dynamite charge is the blasting cap or detonator, which is charged with a powerful explosive and either fired by a safety fuse or electric spark. The resulting shock and intense heat fires or detonates the dynamite. Electric caps are normally used on modern construction work, and the standard caps are insulated against water but are not waterproof for underwater firing. The caps are equipped with wires from 4 to 20 ft. long, varying in 2-ft. increments, and are interconnected through a parallel or series circuit for firing from an electric source. Series circuits are usually fired by blasting machines, but, with parallel circuits, connection to a power supply is the usual practice. As a safety precaution, circuits are tested with a galvanometer before firing. Electric delay caps are designed for successive firing up to six intervals, after receiving the initial firing impulse. A representative layout of a blast as employed on the Norris Dam quarry, using the bench method, consisted of one, two, or three rows of holes about 8 ft. from the face and 8 ft. apart, all parallel to the face. In each row the holes were 30 ft. deep and 6 ft. on centers, and the explosives were distributed in the holes to break up the rock as much as possible and reduce the need for secondary shooting.

On foundation work for dams special precautions are required to prevent shattering of the base. As a rule, the bulk of the rock to be excavated is blasted with heavier charges, and this is followed by lighter blasting as the final grade is approached.

At Wheeler Dam the deep excavation for the draft tubes required special care in not disturbing the adjacent foundation for the intake structure. Along the border line of these two areas a deep cut was made by line drilling a vertical face with $2\frac{1}{4}$-in. holes at $4\frac{1}{2}$-in. centers. The rock to be excavated was then drilled with 6- to 8-ft. deep holes with the space between holes equal to two-thirds of the depth. All these holes were located outside of a zone 30 ft. wide and adjacent to the line

drilling, and this zone was not drilled. The shattering effect of the other holes was depended upon to break up the rock in this zone, and this arrangement plus the line drilling prevented destructive shocks from being transmitted into the foundation for the intake structure.

Table 34 shows the amount of drilling and explosives per cubic yard of rock excavation as experienced on a number of large projects.

TABLE 34.—DRILLING AND EXPLOSIVES PER CUBIC YARD OF ROCK

Project	Type of rock	Type of excavation	Explosives required, lb. per cu. yd. of rock excavated	Lin. ft. of hole required, per cu. yd. of rock excavated
Wheeler Dam*	Limestone	Powerhouse foundation	0.500	1.03
		Dam foundation	0.628	1.63
Norris Dam*	Dolomite	Open quarry	0.692	0.84
Pickwick Landing Dam*	Limestone	Lock foundation	0.671	2.32
		Powerhouse foundation	0.650	1.59
Guntersville Dam*	Limestone	Lock foundation	0.403	2.95
Chickamauga Dam†	Limestone	Lock foundation	0.439	0.356
		Open quarry	0.435	0.506

* Holes drilled with 2½-in. bits.
† Holes drilled with 4½-in. bits.

A great many standard precautions have been developed on most jobs for the handling of explosives. These include protection from sparks and rain while hauling, avoiding shocks, storing in a dry, well-ventilated place at a safe distance from other buildings, and particularly the hauling of detonators and explosives in separate vehicles and their storage in different buildings.

CHAPTER XVIII

FOUNDATIONS—GROUTING AND CONSOLIDATION

One of the most complicated phases of heavy construction relates to proper treatment of the foundation to develop adequate stability for the superimposed structure. This applies particularly to hydraulic structures where surface water, ground water, seepage, or various forms of instability of earth or soil are involved. In the case of a dam subjected to vertical and horizontal loading, as well as uplift, the necessary preparation of the foundation to resist these forces is sometimes exceedingly difficult. Seepage may appear to be of minor importance at the moment, but if acting over a long period of time it may be a major factor leading to the eventual destruction of the dam.

Careful planning is of extreme importance in dealing with foundations because in many cases the work is entirely underground and there is no obvious indication of accomplishment or any visual evidence of the money spent. A drilling and grouting program, for example, may cost several hundred thousand dollars, but after the work is completed there is no evidence of it ever having been done, and only long periods of time will disclose the effectiveness of the expenditures.

The foundation constructor must treat with many unforeseen contingencies and hidden forces. Unless he has thoroughly planned and investigated every step of his operations, he may suddenly discover that he is faced with failure and his work must be either done over or abandoned. For example, on one project the excavation was carried along well ahead of construction and when the unsuspected forces of the sun's heat came into action, and the newly exposed surface was subjected to temperature changes from day to night, the surface spalled and became unsuitable for resisting the sliding forces on the dam. At the same time the exposed rock face, which for centuries had been subjected to the pressures of superimposed earth and rock, contained internal stresses which were finally being liberated,

and this caused the rock structure to crack. A deep cutoff trench had been excavated, as required, and provided the necessary freedom for the exposed rock layers to expand and shear along a plane on a level with the base of the trench. This new fracture also destroyed the effectiveness of the rock to support the horizontal forces on the dam and made it necessary to excavate over the entire area down to the base of the cutoff trench. The new trench was thereafter excavated only as it was feasible to refill it immediately with concrete.

In the construction of a dam it is well to keep in mind that the river may originally have found its bed by scouring down through a fissure in the rock formation, and when the bed is finally exposed a continuation of that fissure may still be in evidence. In such cases it is important to clean out any disintegrated or broken rock along the fault zone and to refill it with concrete and high-pressure grout to prevent any possible undercutting or destructive seepage in the years to come.

Grouting.—Even in so-called sound rock formations there are many seams and crevices through which water from the reservoir can percolate after the dam is built. It has become almost universal practice of late to grout such seams carefully for two purposes: (1) to prevent underground water passages; and (2) to render the foundation impermeable and thus reduce hydrostatic uplift under the dam. As a rule the fissures and major seams in the rock structure have been located in advance by means of exploratory drilling, and the grouting is directed to seal such openings most effectively. This is generally carried out, as in the case of Norris Dam (Fig. 80), by first grouting, in advance of dam construction, the upper strata of rock under low pressure of 30 to 50 lb. per sq. in., to consolidate the upper structure. After the base of the dam has been constructed, deep holes are later drilled through the upper grout curtain down into the underlying strata and these are filled with grout at higher pressures up to 150 lb. per sq. in. In some cases where there is no danger of lifting the strata or otherwise deforming the rock structure, pressures up to 500 lb. per sq. in. may be used. Uplift gauges should be installed to indicate any tendency for the surface rock to lift when applying a high pressure over an extensive area.

The consistency of the grout depends upon the size of the seam or cavity. For fine seams 1 part of cement to 10 parts of water

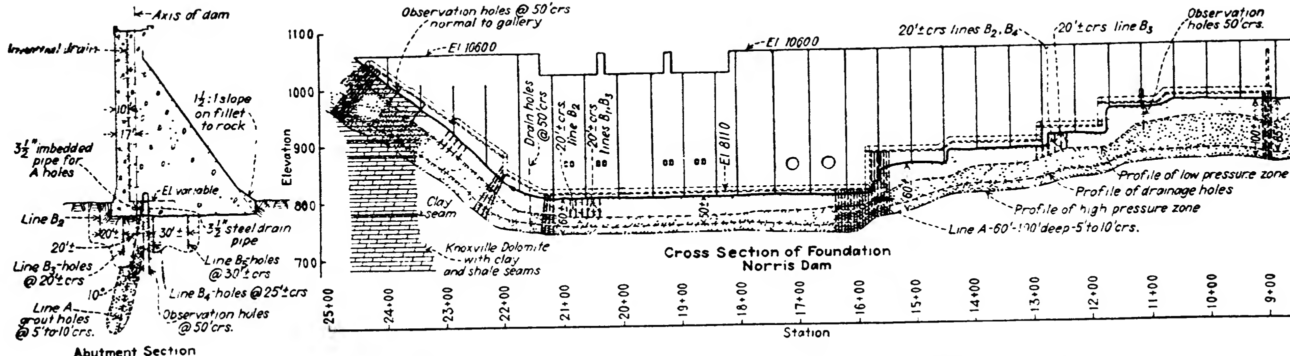


FIG. 80.—Diagram of grout curtain under Norris Dam to cut off seepage through rock fissures.

NOTES—A line holes for grout curtain spaced at approximately 5- to 10-ft. centers, minimum depth 60 ft., minimum diameter 3 in., grouted from gallery through imbedded 3½-in. pipe under high pressure. Maximum pressure, 150 lb. per sq. in. Drilled and grouted holes at 10-ft. centers before drilling and grouting of holes in between. *B* holes, holes for near surface blanket grouting, drilled with jackhammers before concrete is placed. Maximum depth, 30 ft. Grouted under low pressure (30 lb. per sq. in.). Spacing and depth of holes varied to suit rock conditions. Drain holes, 3 in. minimum diameter, 50 to 85 ft. deep at 50-ft. centers, drilled from gallery through imbedded 3½-in. pipe after high-pressure grouting was completed.

(by volume) may be required to obtain penetration of the grout. Normally, a mixture of 1 part cement to 1½ parts water is most effective. In larger seams a 1:1 mix, or even ¾ part water to 1 part cement may be used. In most cases it is best to use finely ground cement passing a 200-mesh sieve and, in any case, the cement should be screened through about a 28-mesh sieve to take out lumps.

Pumping into a hole should be continuous, as short stoppages will allow plugs to form and the seams to be sealed prematurely. In all cases the grout must be applied at a point below the overburden where the grout pipe may be effectively sealed into the rock so that no back pressure or loss into the overburden develops.

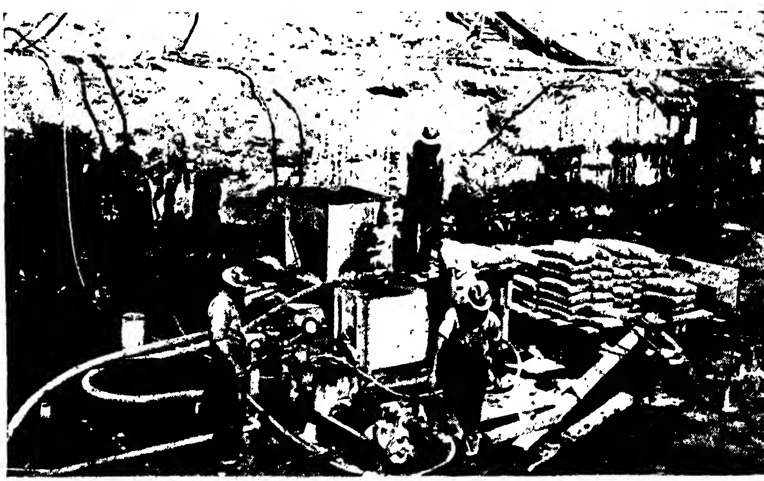


Fig. 81.—Cement grout mixer and pump.

A grout mixer usually has two compartments (Fig. 81), one for mixing a charge and the other to hold a fully mixed charge which is fed to the pump. The mixed material must be continually agitated during pumping. The pump should be equipped so as to furnish a steady and dependable pressure and supply and be capable of pumping against various pressures. Hose is more suitable than rigid pipe for handling grout. Lines are normally about 500 ft. long, but may be increased to 800 ft. in cool weather. The rate of pumping grout depends on so many conditions that no rule can be established, but, in general, between 25 and 50 cu. ft. of grout can be pumped per hour within the pressure range of 25 to 150 lb. per sq. in.

In some cases, for economy, it may be desirable to mix a cheap filler material with the grout. Sand is generally unsuitable for thin seams. For grouting the reservoir rim at Norris Dam, James S. Lewis devised a successful method of utilizing a rock-flour by-product from the aggregate crushing plant. This material was thoroughly mixed with water and added to the cement and water mixture in the grout mixer. The mix usually consisted of 2 parts cement, 2 parts rock flour, and 5 parts of water, proportioned by volume. Three per cent of calcium chloride was added to hasten the setting. Careful tests should precede the use of any such filler material to determine its suitability in the mix and in the hardened product.

At Norris Dam some of the horizontal seams in the rock contained in their natural state fine layers of clay, varying from almost nothing to 2 or 3 in. in thickness, and it was necessary to clean out this clay before grout could be injected to cement the two layers of rock together. This removal was accomplished by a novel system of washing the seams. Three or more adjacent drill holes were arranged so the outer ones were connected to an air supply and the center hole to water under pressure. By reversing the direction of air in the feeders, the surging of the water loosened the mud and other materials and the pressure forced it out through adjacent holes.

As a rule, grouting technique is highly specialized and requires the development of a variety of special equipment to suit the particular conditions. At Norris Dam, for example, the use of 36-in. core-drill holes was introduced to permit visual inspection of the original formation and later to check the effectiveness of the grouting. Furthermore, a grout mixer and rock-flour mixer of special design were used as well as seam washers, mechanical and visual periscope explorers and seam locaters, electrical explorers and seam locaters, special packers and expanders for connecting the pipe which carries the grout to the rock structure, and upheaval gauges. The subject of grouting and suitable equipment has been covered in valuable detail by J. B. Hays in *Civil Engineering* of May, 1939, and by J. S. Lewis, Jr., in A.S.C.E. *Proceedings* of March, 1940.

Clay Grouting.—At Madden Dam in the Canal Zone the permeability of the limestone along the ridges of the reservoir rim made extensive grouting necessary to seal large seams and

solution channels which were usually not more than 5 to 20 ft. below the water surface when the reservoir was full. Most of these caverns were coated with a loamy sand and were of such size as to make cement or asphalt grouting unsuitable and too expensive. The presence of large quantities of clay directed efforts toward using it for grouting, and after some study a satisfactory technique was developed. Clay and water were mixed in a 1-yd. mixer tank by an agitator and pumped into drill holes under pressure. The mixture, in general, was 55 per cent water (by weight) and was injected into the holes by air at a pressure of 110 lb. per sq. in. Where the back pressure was lower, say from 50 to 85 lb. per sq. in., a thicker grout containing 45 to 50 per cent water was used, and where back pressures were less than 50 lb. a very thick grout containing, in some cases, only 43 per cent water was pumped into the holes. All holes were finally subjected to 300-lb. pressure applied by grout with 50 per cent water. Where the drill holes hit large caverns a thick partly mixed grout was poured down the hole until it was filled, and then pressure was applied and a thick grout pumped until the desired back pressure was developed. Two pumps were used, one a double-acting piston pump, which developed up to 150 lb. of pressure and pumped thick grout through a 6-in. discharge line; and the other a high-pressure pump capable of pumping through a 3-in. discharge at 300 lb. per sq. in. In general, the clay grout consolidated well and formed a good bond with the walls or seams and caverns. Penetration in thin seams extended up to 50 ft. from the drill holes. On the Madden project, 70,000 cu. yd. of grout was placed at an average cost, exclusive of drilling, of $5.35 per cubic yard. Clay was delivered under contract at $2 per cubic yard and is included in the cost figure, the clay having special characteristics which made it more suitable than other materials obtainable at lesser cost in the immediate vicinity of the work. The plant capacity was 100 cu. yd. per 8-hr. day, under normal conditions.

The main disadvantage of clay grouting is that it is not effective in plugging seams containing running water and it has very little resistance to erosion.

Asphalt Grouting.—Asphalt grouting has been used to a considerable extent in this country and is better than cement grouting for fissures and broken rock where there is ground water

flowing at an appreciable velocity. Asphalt is pumped into the ground as a hot fluid and solidifies under water in cooling (see Fig. 82). Asphalt is obtainable in many varieties from a thick fluid to brittle or oxidized grades. It is important that the right kind be used to obtain the most suitable consistency for grouting purposes. As a rule, the most effective asphalt grout is one which does not become hardened to brittleness, but which becomes stiff.

Placing of asphalt grout is facilitated by a steam line running through the drill-hole liner or by means of a patented process, developed by G. W. Christians, consisting of an electric resistance wire suspended in the liner pipe, with the pipe completing the

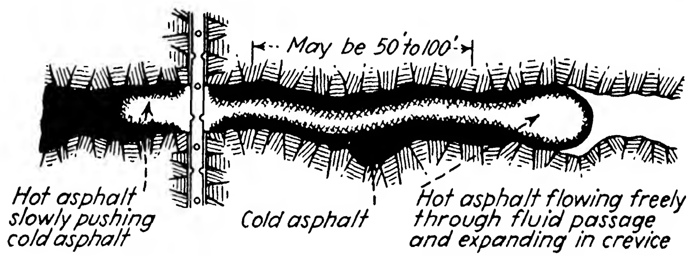


FIG. 82.—Hot asphalt expanding in a rock crevice.

electrical circuit, thereby keeping the asphalt hot. The latter method provides assurance against plugged pipe lines because, by turning on the current, any consolidated asphalt in the pipes can be heated up and grouting resumed. In some cases, this arrangement may be applied where the pipe is left in the ground for 6 months or a year, and if any further leakage develops the pipe may be reheated and the formation regrouted. The feed pipe is perforated at the lower end and asphalt enters the various fissures in the rock through these perforations. Hot asphalt is usually pumped in at pressures of 50 lb. per sq. in. and in a 2- or 3-in. seam it can be forced laterally from 100 to 200 ft. Some of the deposited asphalt, if of the type which does not completely solidify, can be moved farther into the crevices after it has cooled at pressures of 200 lb. per sq. in.

The steam-heating system, using one pipe within another to form a closed circulation for the steam and lowered into the well casing into which the hot asphalt is poured, is particularly useful where large quantities of asphalt are needed to fill cavernous formations.

Special Materials.—Sometimes the fissures are so large that special mixtures of a matted material and other binders are used first to fill the major part of a fissure or leak, and after the bulk of the water has been cut off, a cementing grout is applied. The high expansion characteristics of volcanic ash have been used at times with considerable success.

Consolidation or Cementation Processes.—There are two chemical processes which have been used successfully for consolidating water-bearing or loose formations. One of these is known as the Francois cementation process, a chemical treatment which usually precedes cement grouting in fissures, seams or broken rocks, using a special patented chemical compound. The chemicals used in pretreatment form a colloidal precipitate which quickly sets and seals the fine cracks and openings and lines large seams and cavities. The deposit serves to lubricate the surfaces and allow deeper than normal penetration of the cement grout. This process has been used with pressure up to 2,000 lb. per sq. in. and higher.

A second chemical process, known as the Jorgensen process, is claimed to be particularly adapted to solidifying porous materials and overburden such as gravel, sand and broken rock into a concrete-like mass by injecting a sodium silicate solution followed by the injection of a salt brine or calcium chloride solution. This method has been used successfully in Europe and has recently been patented in this country. The following report has been given out regarding this process:

The chemicals will solidify under water, although water tends to reduce the range and effectiveness of the process. For use in fine wet sand it is preferable to remove the water in the formation, if this is feasible. In large cavities this method of treatment is not applicable, as its action is in cementing or gluing material together, and it will not form large blocks of solid materials. Most chemicals used in these processes are heavier than water and they tend to displace it, thus making an effective seal in material carrying only a moderate amount of water. This process has been used successfully in solidifying material under bridge piers, the edges of deep trenches, and to develop a waterproofing for leaky concrete and masonry in tunnels and mine shafts. The cost of solidifying material is said to range from $12 to $22 per cubic yard, including drilling.

In Russia, the injection of a water-glass solution followed by a salt brine, sometimes containing cement, was used on the Moscow subway; this mixture was injected into a quicksand formation and caused the formation to solidify within 15 to 20 min. About 90 gal. of chemicals was used to 1 cu. yd. of sand. Progress of solidification was at a rate of about 2½ yd. per hr.

Freezing Earth.—A process of freezing used in 1933 for driving a 16-ft. shaft through quicksand for the Moscow subway in Russia has been carried to new developments recently in connection with the construction of the Grand Coulee Dam on the Columbia River in Washington. The construction work there involved the removal of a large layer of overburden of glacial silt. This silt is a fine rock flour which, when wet, is fluid and has a slippery consistency. As the excavation proceeded, part of the overburden began to flow into the working area, and this soon reached proportions where, without any treatment, it was estimated that from 30,000 to 200,000 cu. yd. of earth would slide through a deep rock gulch into the excavation area. After various methods of holding the impending slide had been considered it was decided to utilize the high moisture content of the material as a means of freezing the formation into an arched dam, abutting into a rock formation at each end, and thereby hold back the slide.

This arch dam of frozen earth, 20 ft. thick, 100 ft. long, and about 50 ft. high on a 105-ft. radius, is without precedent and was formed by driving 377 freezing points of 3-in. diameter pipe, averaging 43 ft. long, into the earth. These points were placed at 30-in. centers in both directions with about 25 extra points at each abutment, and were connected by 2-in. rubber hose. A salt brine was pumped into the points through 1½-in. pipe within the points, which conducted the brine to within 6 ft. of the bottom of the point where it was discharged into the 3-in. pipe and forced upward through the space between the two pipes and recovered at the top. While considerable movement of the arch during freezing was noted, no serious damage was done and the stability of the frozen dam was sufficient to hold back the slide. To relieve the dam of high fluid pressures, a drainage well was sunk 30 ft. in front of the arch; when excavation below the dam was completed, the water drained out by gravity, and the well was no longer needed. Two refrigerating plants

were used with a combined capacity of 80 tons of ice per day, using ammonia as a refrigerant to cool the salt brine. The freezing was accomplished in less than 20 days. The arch dam was constructed at a cost of about $30,000, and this measure saved the cost of excavating about $100,000 worth of material.

The freezing process of consolidation has been used with great success in Europe for many years for sinking shafts through water-bearing ground to depths of 2,100 ft. A notable shaft-sinking job was performed in 1938 at Gilbertsville Dam by B. W. Goodenough and described in technical publications. A further development in freezing processes was described in *The Engineer*, London, May 19, 1939, as follows:

The first practical application of the freezing process was in England in 1880. Two processes are now available for freezing ground. The Poetsch process and the Dehottay process. In the former, ammonia is generally used as the refrigerating fluid; this is confined to the primary circuit and is used to lower the temperature of a calcium chloride brine which circulates continuously through a refrigerating chamber and thence through pipes installed in four holes sunk at about 3 ft. intervals into the strata to be frozen. Although this process has long been used, it has several weak points. It is slow and consequently expensive; also the power consumption is high. Should a freezing pipe break and brine escape from it, a body of ground will be formed which it will be impossible to freeze, and to remedy this condition will be difficult. The more recently introduced Dehottay process claims to have overcome certain of these troubles. In it carbon dioxide is used as the refrigerating fluid, the brine circuit is done away with, and the carbon dioxide itself circulates through the freezing tubes in the four holes. In this way the power required for the circulation of the brine is saved, the exchange of heat between the ammonia circuit and brine circuit is eliminated, and dangers due to leakage of brine are avoided, escape of CO_2 having no ill effects on the ground.

To sum up, the freezing process can be used under circumstances where no other method could be employed with success—that is, where silt and similar material is found under a high hydrostatic pressure. Its use in constructional work has been small but appears to be increasing. Its main disadvantages are its high cost and the period of time necessary for freezing of the ground to be accomplished.

CHAPTER XIX

CUTOFFS, PILE FOUNDATIONS, AND CAISSONS

Core Walls to Cut Seepage.—Where dams are built on a glacial formation of highly porous gravel or sand, a grouting or chemical process of consolidation is usually out of the question and, as a rule, a steel-sheet-pile interlocking cutoff is driven down from 40 to 60 ft. or sometimes 100 ft. or more into the ground. Extending above the ground surface is either a reinforced concrete core wall or core of impervious clay which, together with the

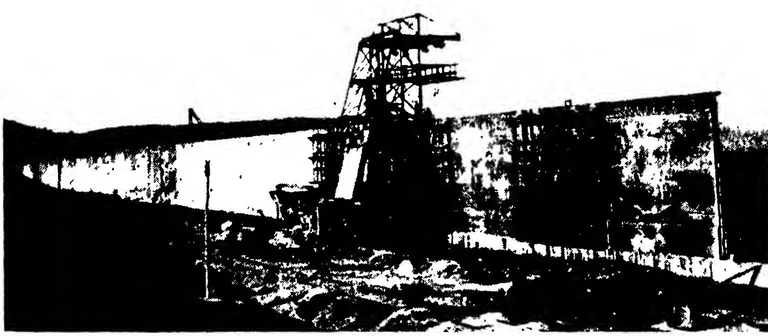


Fig. 83.—Cutoff in earth dam formed by thin concrete wall and sheet piling extending 40 ft. below ground surface.

sheet piling, forms a continuous diaphragm which lengthens the seepage path and reduces percolation through the dam to very small and unobjectionable quantities. Figure 83 shows the simplest type of reinforced concrete core wall as used on the sand dams in Michigan; a special type of concrete core wall was extended down to rock on the Quabbin Dike in Massachusetts. This dam and its location with respect to downstream communities were so important that a cutoff diaphragm extending to solid rock was considered necessary. The overburden was unstable and it was, therefore, necessary to build the cutoff by

lowering cellular sections into place as pneumatic caissons which, after being interconnected and sealed at the bottom, formed an effective diaphragm across the valley.

Special Foundations of Piling.—In many cases it is necessary to relieve the surface ground formations of the duty of carrying a structure and to transmit the loads to some underlying and more stable strata by means of one of several kinds of piles, or heavy piers. The most common type of piling is the timber

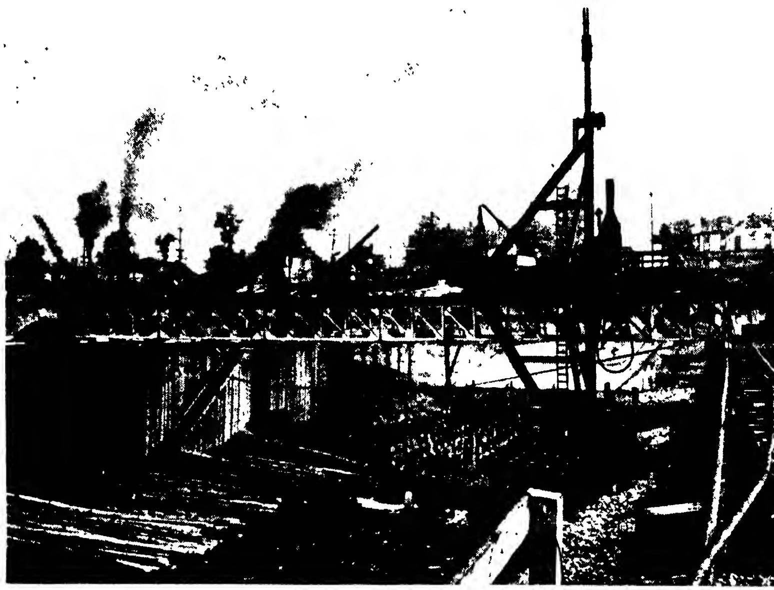


Fig. 84.—Special rig for driving timber foundation piling.

pile, which has been used on such projects as the Alcona Dam in Michigan, where piles 60 ft. long were driven at 2½-ft. centers over an area about 116 by 76 ft. to support a powerhouse structure in a quicksand formation. The driving was done from an overhead traveling bridge prior to unwatering; the water had to remain in place until all the foundation preparations had been completed in order to retain the equilibrium of the earth formations and prevent upheaval of the quicksand. The piles extended through the quicksand to a coarse and sufficiently stable water-bearing sand.

On the Allegheny River Dam No. 3, about 4,420 piles were driven from a similar traveling bridge in the dry. The piles

were located on 4-ft. centers in each direction through 17 ft. of overburden to support this navigation dam, as illustrated in Fig. 84. Where a more permanent type of piling is required, reinforced precast concrete piles are used. In the construction of the Imperial Dam on the Colorado River, near Yuma, Arizona, more than 3,000 piles 45 to 50 ft. long were used, in this case battered in both directions to resist more effectively the hori-

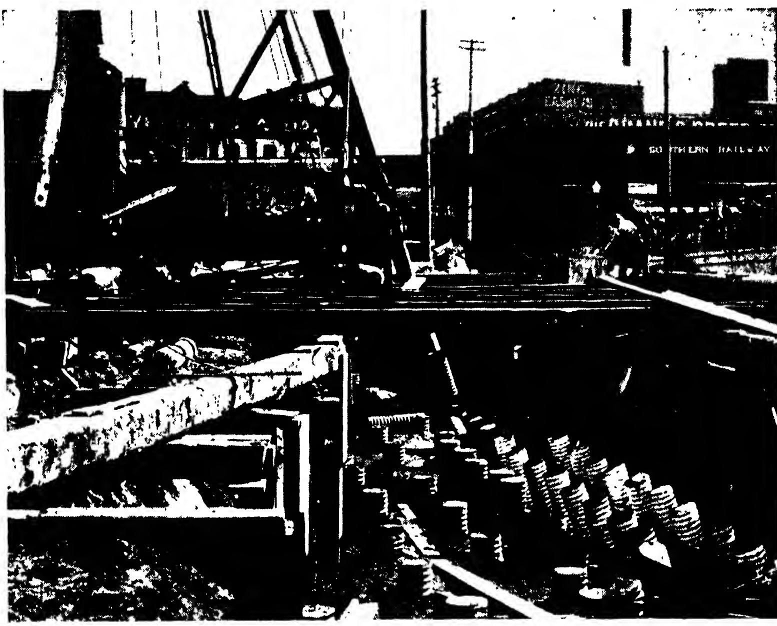


Fig. 85.—Steel cylinders driven with retractable mandrel and then filled with concrete to form Raymond pile.

zontal and vertical components of hydrostatic forces. Concrete piles are generally jetted into place in combination with some driving, a jet pipe being cast in the center of the pile through which water under pressure is fed to its tip.

An effective type of concrete pile which is particularly suited to soil formations which are of such depth and consistency as to make the driving of precast piles difficult has been developed in the Raymond concrete pile (Fig. 85). This consists of a steel shell fitting over a heavy steel mandrel which absorbs the driving blows of a standard pile hammer as the mandrel and shell are driven to place. When the assembly has reached final grade

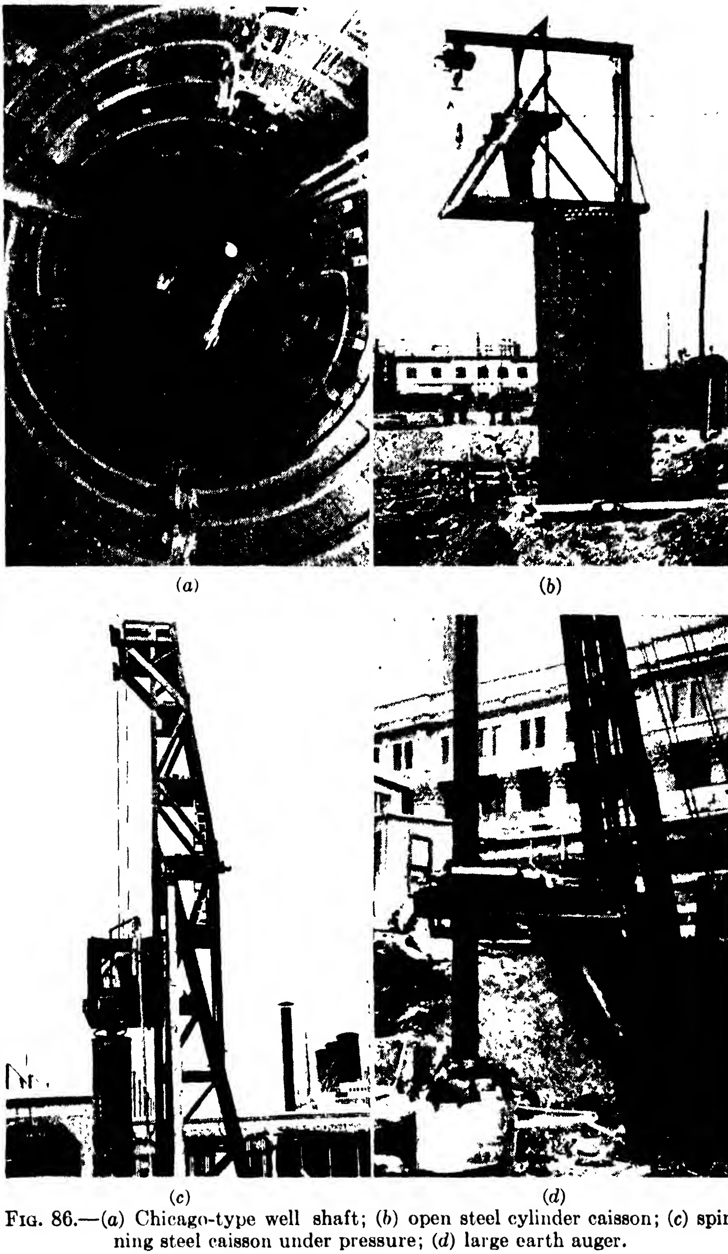
the mandrel is withdrawn, leaving the empty steel shell to be filled with concrete up to the top, developing a satisfactory and permanent concrete pile.

In recent years a better understanding of corrosion, and of the life of steel located underground, has led to considerable use of steel H columns for piles. They are easy to drive and have the highest bearing strength per pile.

Open Shafts for Large Piers.—Where the limited size of standard piles does not provide sufficient bearing power, and larger piers are required, these may be constructed in various ways, as shown in the illustrations. One of the older methods consists of the so-called Chicago well method (Fig. 86*a*) which is a simple system of manual excavation and sheeting of the shaft by means of vertical timbering and horizontal steel hoops, which are wedged against the sheeting. The process of lining usually follows right behind the excavation as soon as depth has been reached for another section. Of course, the formation being penetrated must be stable enough to keep from rising in the hole. Other open-shaft methods consist of sinking steel shells by driving them down with large pile hammers or by means of internal excavation, the earth being removed with a bucket and small hoist mounted on top of the shell (Fig. 86*b*).

Another method of making cylindrical pockets consists of driving a ring of steel sheet piling by using either a slightly curved pile section, where a relatively small diameter is required, or the standard sections to drive a larger cylinder, the lower limit of diameter being the angularity between piles permitted by the interlocks. On several pier jobs a combination of Z piling has been used to form a shaft of special cross section.

More recently a very ingenious method has been developed for sinking large-diameter steel caissons through an unstable overburden by means of a spinning process. This method is called the Montee patented caisson (Fig. 86*c*), and has been used in New York on shells up to 60 and 70 ft. in depth, and from 4 to 8½ ft. in diameter. The cylinder is made of steel plate ⅜ to ½ in. thick, and at the lower end a saw-toothed cutting edge is specially faced with an abrasive metal. The cylinder is clamped by a water-tight connection to a rotating head driven by a 125-hp. electric motor mounted on a skid rig with vertical leads 78 ft. high. The rotating head spins the cylinder through sand, clay, gravel,



(a) (b) (c) (d)

FIG. 86.—(a) Chicago-type well shaft; (b) open steel cylinder caisson; (c) spinning steel caisson under pressure; (d) large earth auger.

boulders, and timber. The inside of the cylinder is partly filled with water, and water is fed directly to the cutting edge through pipes welded on the inside face of the cylinder. This water aids cutting and is supplied through the turning head under pressure of sufficient amount to overcome any tendency for inward caving of the foundation material. In other words, the caisson also dispenses with pneumatic equipment and can be used where such equipment was formerly essential.

The secret of this successful method consists in attaching the caisson to the rotating head with a slight eccentric setting so that, in rotating, the caisson sweeps with an eccentric motion. As a result, only the cutting edge actually encounters a great amount of resistance, as the remaining portion of the cylinder is barely in contact with the wall of earth surrounding the cylinder, since the eccentric motion cuts a hole larger than the diameter of the cylinder. Furthermore, water delivered through the rotating head rises on the outside and lubricates the walls, at the same time bringing up a large part of the earth from the inside. The cylinders are spun down at the rate of 12 to 20 ft. per hour, rotating at a speed of 4 to 11 r.p.m., and it is possible to sink a 65-ft. cylinder in 4 to 6 hr. as compared with 6 to 8 days in sinking a similar cylinder by pneumatic processes.

The development of this spinning method was preceded by the large-diameter churn drills used on the Hudson Tunnel and the large-diameter auger borings for deep pier holes used on the Detroit Post Office (Fig. 86*d*).

Special Caissons.—Practically all the principles which apply to large pier caissons find application at some time or other in the construction of a dam or related works. A brief description of some of the more notable caisson jobs, therefore, is included here.

An unusual type of dam construction was employed on the Montgomery Island Dam in Pennsylvania (Fig. 87), where the overburden was such as to call for construction of the lower part of the dam in the form of cellular boxes which were cast directly on the sand formation and provided with wells through which the sand could be excavated. This caused the boxes to sink and allowed additional lifts of concrete to be placed on top until the base in this manner reached the rock bottom, after which the spillway section of the dam was added at the top. This

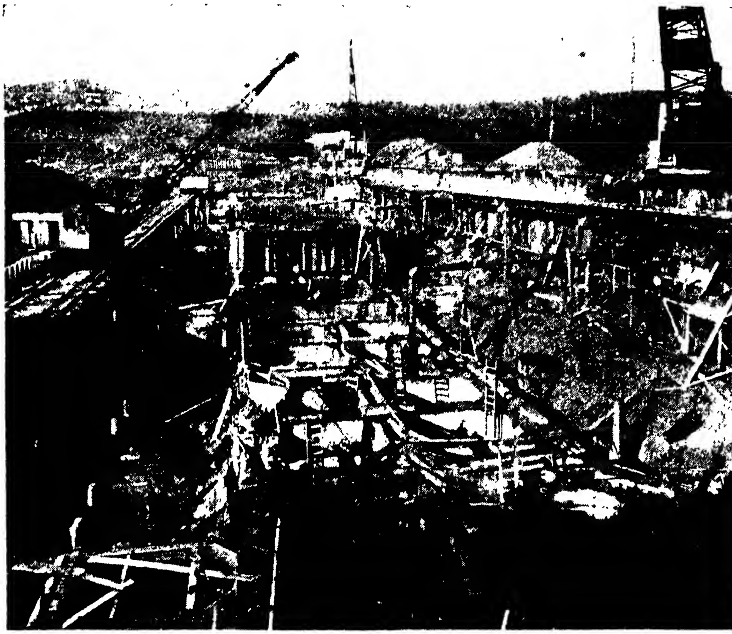


FIG. 87.—Sectional type of cellular base for Montgomery Island Dam.

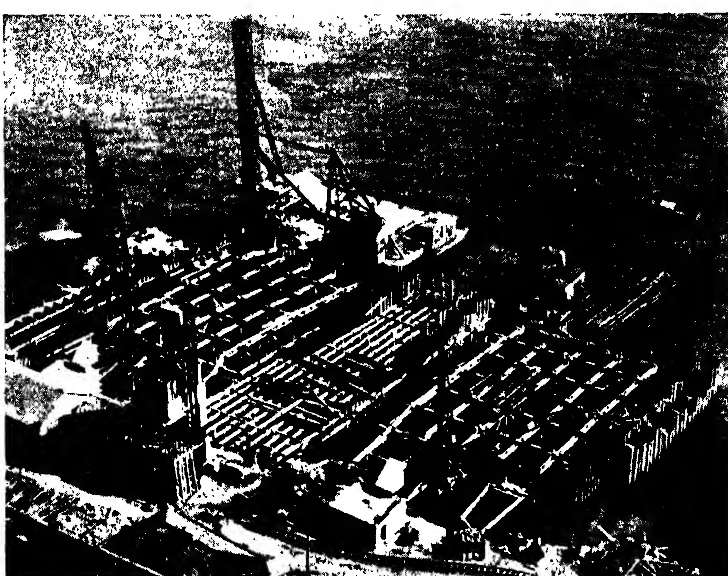


FIG. 88.—Deep open foundation cofferdam for George Washington Bridge Pier.

method of dam construction is probably suited only to certain conditions. On a larger scale project a greater opening up of cofferdam and excavation activities may be justified to a point where heavy production at high speed will produce sufficiently lower unit costs of excavation and concrete placement to offset the greater amount of other work necessary under such a method.

In the case of the Washington Bridge Foundation (Fig. 88), the usual caisson methods were displaced by a cellular sheet-pile cofferdam of exceptional depth and equipped with a system of internal timber framing to withstand the external water loads after the area was unwatered. This method is an adaptation of open-cofferdam and caisson principles and is particularly suitable for exposing small areas where steel cells, stable by themselves, would prove too expensive.

Sand-island Pier Construction.—The process employed at Montgomery Island Dam is similar in principle to the one developed by N. F. Helmers under which a special island of sand is constructed in a river to provide a stable footing through which a pier may be sunk to rock or other sound formation. This "sand island" method (patented) has been used recently on a number of large bridges, including the Suison Bay Bridge in California, the Mississippi River Bridge at New Orleans, and a bridge on the Missouri River near St. Charles. On the Mississippi River Bridge five piers were constructed on a foundation of a mixture of mud, soil, and clay in layers to unknown depth and very unstable and erodible at the surface. The pier foundations were carried to 188 ft. below average high-water level.

As a preliminary step, woven willow mattresses were sunk at each of the pier sites in order to protect the area of the river bed against local scouring due to construction activities. A timber-pile falsework, composed of 110- to 135-ft.-long bents sunk to about 25 ft. penetration and with tops about 4 ft. above normal high water, was constructed with a circular working platform on top. Thereafter cylindrical steel shells were constructed in sections 10 ft. high. These shells were up to 120 ft. in diameter, assembled in the falsework, and were attached one on top of the other to a height of 30 ft. This assembly was then lowered 30 ft., and additional 30-ft. sections were added in similar steps, until the shell was seated firmly on the mattress and the top was a safe distance above water level (see Fig. 89). The assembled

shells were from 70 to 100 ft. in height. The mattress was then cut out along the inside of the shell, and the shell was filled with sand to a point above water level.

The concrete pier caissons were 65 by 102 ft. in area and were sunk inside the shells by dredging sand out through wells left in the caissons, and by building up the caisson walls as the sinking proceeded (see Fig. 90). The concrete caissons were eventually

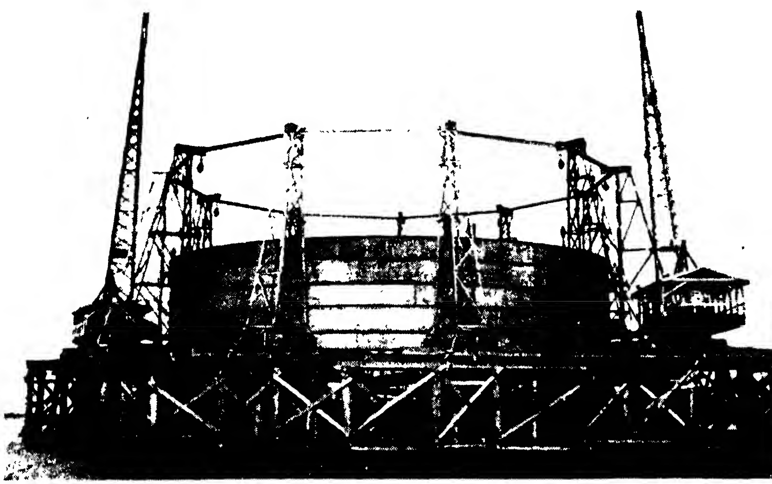


FIG. 89.—Steel shell being lowered into place to provide sand island for construction of bridge pier.

135 ft. high and supported a timber frame 50 ft. high, which served as a cofferdam for later unwatering and erection of the remaining portion of the concrete pier by open-water methods. After a pier was completed, the remaining sand between the completed pier and the steel shell was dredged out and the shell was removed for reuse by detaching the lowest section accessible to a diver.

This method of caisson work reduces the danger of tipping and blowouts when working through unstable or soft material. Hydrostatic forces are balanced inside and out during practically all the operations, and if any damage should occur before stability is obtained by filling the shell with sand, such damage occurs only on temporary construction and not on the main pier. As an example of progress, pier No. 2 on the Mississippi River

Bridge was constructed in 135 days from the time falsework was started until the pier was completed above water level.

Pneumatic Caissons.—Where a pier caisson is being lowered to rock by means of internal excavation and is penetrating an unstable or water-bearing material which tends to flow upward into the excavated space, air pressure is necessary to hold the material in place and to maintain a working chamber in which men can carry on the excavation. A simple pneumatic caisson consists of a cutting edge at the bottom of the side-walls and a

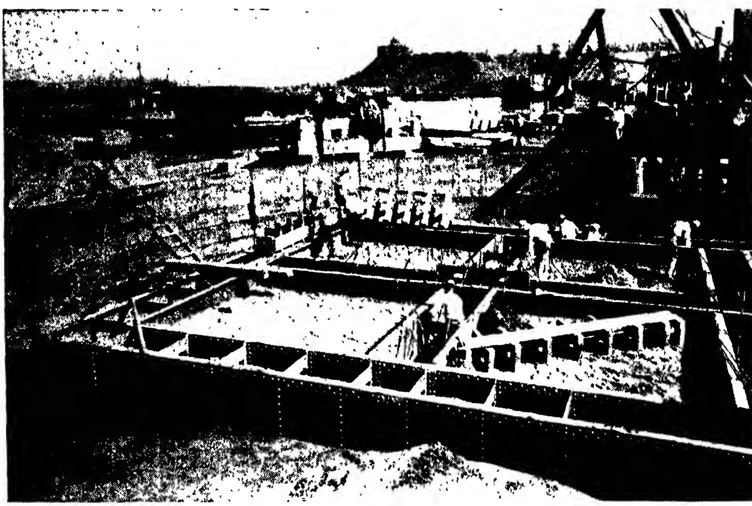


FIG. 90.—Cutting edge on sand island; first step in lowering concrete pier.

roof about 6 to 7 ft. above this edge to develop a working chamber. All this structure forms part of the ultimate pier, and concrete is added on top of the roof to overcome buoyancy and to furnish the necessary load to maintain the sinking process. The men inside the working chamber fill buckets with muck and excavated materials and these are carried out through so-called mud locks built into the roof, which are designed to permit disposal of the excavated material without loss of air pressure. Similarly, men may enter or leave the working chamber through a lock without loss of pressure inside. Reliability of a low-pressure air supply to the working chamber is a prerequisite, and as a rule oil-driven engines are used, together with such electric-driven engines for high-pressure tools and other purposes

as will not handicap the operations or endanger the workmen if the power should go off.

In the case of air locks used to sink the caissons for the Pennsylvania Railroad bridge over the Passaic River in New Jersey, working pressures ranged from 9 to 27 lb. per square inch. Three caissons, two of them 36 by 98 ft. and one 24 by 87 ft., were sunk to a level of 69 ft. below sea level. The rate of sinking was 2 to 2½ ft. per day of 24 hr., 6 days per week, and the sinking for each of the three piers took 40, 45, and 50 days respectively.

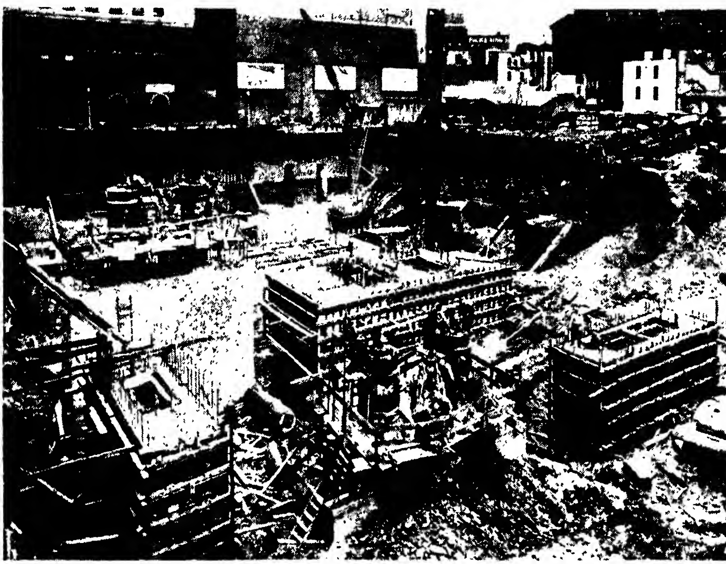


Fig. 91.—Pneumatic caisson piers for Gulf Oil Building. Note mud locks in foreground.

The air-lock caissons used on the Gulf Oil Building in Pittsburgh (Fig. 91), were sunk through 70 ft. of mud and clay to a sound bearing.

Compressed-air Regulations.—Construction hazards are greatly intensified in compressed-air work in tunnels, pneumatic caissons, and the like. The hazards do not merely include all of the possibilities of blowouts, caisson tipping, and similar working conditions, but also the exposure of the laborers to caisson disease. It is standard practice to admit laborers through compression chambers and release them from the caisson through decompression chambers, under medical supervision and in

accordance with state regulations as to rates of compression and decompression. Decompression is usually limited to a rate of 3 lb. in 2 min. for pressures of 36 lb. or less, while 1 lb. per min. is the required rate for pressures in excess of 36 lb.

Eighteen pounds pressure is generally considered the critical pressure in compressed-air work. Above 18 lb., special regulations for increased labor rates, shorter shift hours, and more shift changes result in greatly increased cost, while below 18 lb. normal rates apply. In the pneumatic-caisson construction of the Quabbin Dike core walls in Massachusetts it proved economical to provide sufficient pump capacity to lower the ground water to keep working pressures below 18 lb. This was accomplished by pumping at 1,700 gal. per min. for 5 months preceding the main operations and at 3,500 gal. per min. during the work, these precautions having been prompted by the results obtained in sinking an experimental caisson about a year before the main job was undertaken.

Table 35 gives the requirements of New York State for hours of labor in compressed air as related to an 8-hr. shift period.

TABLE 35.—COMPRESSED-AIR REGULATIONS, NEW YORK STATE

Pressures, pounds per square inch	Hours of work and rest			
	Working hours, maximum, total	Working hours, maximum, first shift	Hours rest in open air between shifts	Working hours, maximum, second shift
Normal to 18	8	4	½	4
18 to 26	6	3	1	3
26 to 33	4	2	2	2
33 to 38	3	1½	3	1½
38 to 43	2	1	4	1
43 to 48	1½	¾	5	¾
48 to 50	1	½	6	½

San Francisco-Oakland Bridge Caissons.—An outstanding piece of work with large caissons was the San Francisco-Oakland Bay Bridge (Fig. 92), where four piers were sunk, ranging from 110 to 170 ft., and three exceeded depths of 200 ft., up to 230 ft. A maximum depth of 150 ft. of mud and clay overburden

was encountered, and work was carried on in water depths up to 105 ft. A special type of caisson was developed for this job. Two of the caissons were 74 by 127 ft. in plan, one of them 92 by 197 ft. in plan, and three others of somewhat smaller dimensions. Each caisson, in general, consisted of a group of 15-ft.-diameter cylindrical steel cells spaced 17 ft. 6 in. in each direction, with the spaces between cells arranged for filling with concrete to the proper height as sinking progressed. The cells themselves were topped with removable steel domes which, when

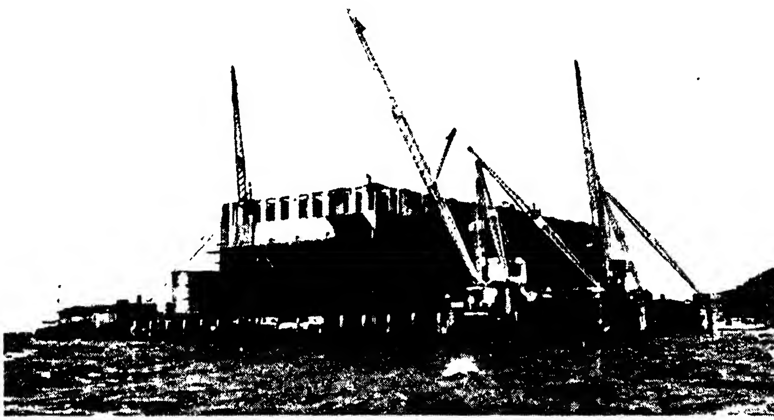


Fig. 92.—Lowering floating caisson for San Francisco-Oakland Bay bridge pier. Derricks being supported on long piling and gravel-filled steel cylinders.

attached, allowed application of air pressure inside to regulate flotation while dredging was progressing through adjacent open cells. The cutting edge consisted of box girders with adapter sections connecting the square cells of the cutting edges with the cylinders. This system was built up into a single boxlike structural steel unit at a shipyard and later launched and floated to position.

It was necessary to hold the caisson against currents running up to 10½ miles per hour. The outside walls were carried to the top of the domes and concrete placed between the cells, or dredging wells, in order to sink the caisson. The tops of the cylinders and outside walls were extended from time to time as sinking progressed through the release of air. Most of the caissons required 5 to 6 months from the time they were delivered to the site until they were seated on the rock bottom. One

110-ft. caisson required only 2 months, whereas one 210-ft. caisson required 11 months.

The chief advantage of this type of caisson is that it is not normally necessary to work men at the bottom under air pressure, but in case of necessity it can be fitted with air locks within limiting depths of pneumatic work. The air pressure in the cells serves as a brake against sudden listing of the caisson, provides control in the cells to correct any list, and will hold the caisson level while sealing on sloping rock.

The engineers in charge of this work have generously disclosed their experiences and point out that:

1. When going through a non-homogeneous material the stability of the caisson is indeterminate, and the operations should be planned so as to minimize the attendant hazards.
2. It is necessary to keep the caisson weight low and the center of gravity as near the cutting edge as possible.
3. It is desirable to maintain symmetry at the cutting edge level. If this is not practicable, provisions should be made rapidly to restore symmetry if necessary.
4. Sudden movements of materials should be avoided. In soft materials, dredging should be from the center gradually and evenly to relieve the cutting edge pressure, allowing the caisson to sink evenly.
5. Dredging should be by sinking opposite ends of the caisson in succession to reduce the probability of tipping sidewise.
6. Undercutting at the outside cutting edges should be kept to a minimum.
7. Attempts to speed up the operations are responsible for most caisson accidents.

Danish Caisson for Bridge Piers.—An open caisson of unique type 145 by 73 ft. was used for the Little Belt Bridge piers in Denmark. The caisson was partially built upside down for easy launching and was made up of about 4-ft.-diameter steel cylinders set side by side to form cellular side walls extending 23 ft. below the concrete roof of the working chamber. The launched caisson weighed 7,000 tons. It was floated to shallow water, capsized, tipped upright, and part of the pier built up while the side-wall cylinders were extended upward above the water line. It was then placed in its position at the bridge site.

The caisson was sunk through the soft underwater formation by means of drills and water jets reaching through the cylinders in the side walls which loosened the material, after which it was carried to the surface by means of compressed air. As the caisson sank, the cylindrical side walls were extended upward, and buoyancy was controlled by building up the pier structure within the caisson walls. After the caisson had reached the bottom it was opened, and excavation and concreting operations were executed in the dry and without the use of compressed air. A limiting condition in the work was the state regulation that the caissons be adaptable to compressed-air work, but be used only in cases of necessity. After the caisson was in place, the side-wall cylinder extensions were removed, and the remainder of the pier was constructed above water. Building one pier required a total time of 2 years. The base of the foundation was 130 ft. below the water surface.

Underwater Work by Divers.—The use of divers is becoming increasingly important because of the more difficult underwater work which is being attempted on modern structures. Visual inspection of deep foundations for massive structures is imperative as a means of insuring the safety of the structure. Normally the maximum working depth is about 125 ft., although greater depths have been attained, notably on the foundation inspection for the San Francisco-Oakland Bay Bridge, where a diver reached a maximum depth of 242 ft.

A large variety of work can be performed under water, including the cutting of steel by means of an oxyelectric torch, which has made possible fast and inexpensive cutting and removal of steel. The electric-arc torch is virtually a miniature electric furnace, and special precautions are necessary in handling it. This torch uses the metal to be cut as the ground electrode and the cutting action is produced when the carbon electrode at the end of the torch comes close to the metal and high-pressure oxygen is jetted from the torch. A diver who is expert in handling this torch can hold it at the proper distance, about ¼ in. from the metal, gauging the distance by the sound developed by the arc.

The oxyelectric torch was used to cut the steel cofferdam piles on the George Washington Bridge when it was found to be

impractical to pull them. It was also used on the Marine Parkway Bridge in New York where 2,118 piles were cut off 30 ft. below the water surface in 40 working days. An average of 60 sheet piles were cut per day of one shift, and the actual cutting time was about 3 hr. net per day, making the rate of cutting 20 sheet piles per hour with one torch.

CHAPTER XX

CRUSHING, SCREENING, AND STORING OF AGGREGATES

Crushing and screening of aggregates may appear to be a rough and haphazard operation on a job, but it is actually a manufacturing process capable of scientific and accurate analysis.

In planning a large crushing operation the economics of the related quarrying of the rock is directly involved and governs the selection of the crushing machinery. A careful study of the best combination for primary and secondary crushing may justify the installation of a larger crusher to receive larger pieces of rock from the quarry, thus reducing secondary blasting. Such blasting generally costs about five times as much as primary blasting, and a reduction in this expense may justify a substantial increase in investment in the crushing plant.

The first step in planning a crushing plant should be the preparation of a line diagram showing the various steps of crushing and screening, as shown in Fig. 93, taking account of the character of the rock, the quantity and rate of crushing, the economics of the quarry operation, and the desired sizes and gradation of products.

A crushing and screening plant should be designed with some excess capacity over the expected continuous consumption, because the intermittent feed into the primary crusher may cause surging overloads on the belt conveyors and screens. The plant should also be capable of catching up with consumption after shutdowns.

A modern stone and sand crushing plant usually consists of the following component parts: Primary crusher, scalping screen, secondary crusher, belt conveyors (see Chap. XXIV), sizing screens, sand mills, sand screens, classifiers or washers, storage piles, reclaiming system, and means for disposing of waste. In arranging these various parts, accessibility, ease of maintenance, flexibility, and the most direct means of handling the materials are major considerations.

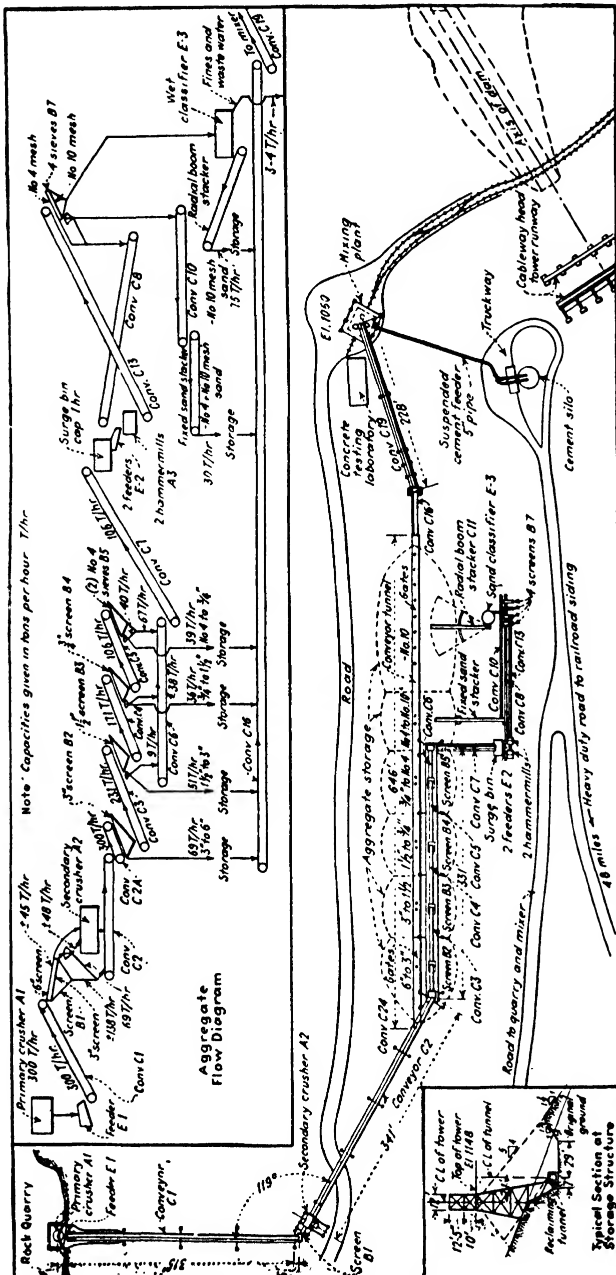


FIG. 93.—Aggregate flow diagram (at top) used in planning crushing and screening plant for Norris Dam; plan of adopted layout at bottom.

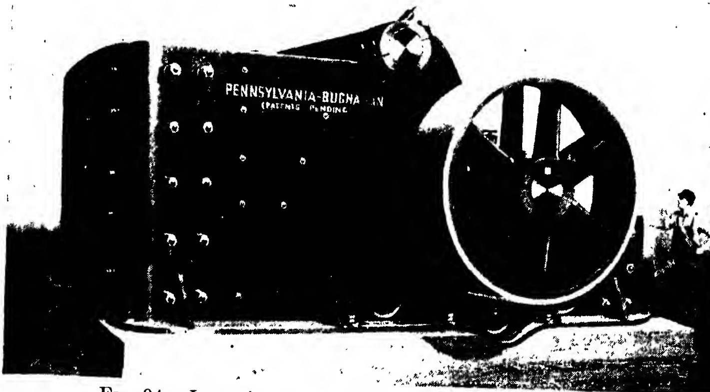


FIG. 94.—Large jaw crusher for primary breaking of rock.

Primary Crushers.—The primary crusher of the jaw or gyratory type is installed with its top below the level of the quarry floor to permit direct loading from trucks, wagons or railroad cars into a hopper above the crusher. A jaw crusher (Fig. 94) can generally take larger pieces but has considerably less capacity than a gyratory crusher. The gyratory (Fig. 95) consists of a heavy conical head suspended from an overhead spider and designed to rotate with an oscillatory motion; it can take rocks up to 5 ft. in diameter in the larger sizes. Primary crushers should be equipped with reversing switches on the motors to release a stalled overload. However, sometimes this expedient is not sufficient, and a heavy hoist-operated hook suspended over the crusher is generally provided for pulling up oversized rock and elongated pieces which occasionally bridge the opening.

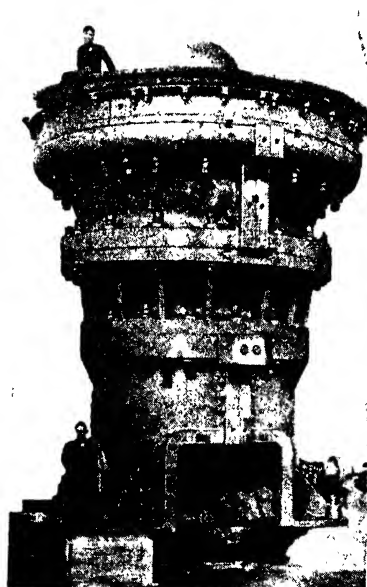


FIG. 95.—Heavy-duty 60-in. gyratory crusher for primary crushing.

TABLE 36.—TABLE OF STANDARD ROCK CRUSHERS
(For coarse and intermediate sizes of product)

Type	Manufacturers' rating size or type	Size of inlet openings, in.	Discharge opening, in.		Capacity, tons per hr.		Required hp.	Approx. net weight of crusher, lb.
			Fine	Coarse	Fine	Coarse		
Gyratory	30	30 by 90	4	6½	235	450	175	169,000
(Coarse)	36	36 by 126	5	6⅝	365	525	225	263,000
(Rated by width of	42	42 by 142	5½	6⅝	475	615	275	286,000
inlet opening in	50	50 to 162	6	7¼	745	845	300	575,000
inches)	54	54 by 162	6¼	8	875	1,050	300	630,000
	60	60 by 174	6¼	10	990	1,440	300	725,000
Jaw	See	30 by 36	5	7	90	125	72	74,500
(Coarse)	next	30 by 48	5	7	120	225	112	121,500
(Rated by size of in-	col.	36 by 42	5	8	108	235	105	113,000
let opening in		42 by 48	6	10	150	320	134	173,000
inches)		48 by 60	6	9	175	290	190	221,000
		60 by 84	7	10	285	450	246	456,000
Gyratory	6	6 by 40	½	1½	24	69	75	33,500
(Intermediate)	10	10 by 52	1⅛	2½	100	214	150	67,000
(Rated by width of inlet opening)	18	18 by 68	1¾	4	310	735	200	187,000
Symons cone	24	3	½	1½	25	60	30	10,500
(Intermediate)	36	4½	½	2	40	95	60	21,000
(Rated by bottom	48	6¾	½	2	80	185	100	35,000
diameter of head	66	9¾	⅝	2½	160	450	200	85,000
in inches)	84	14	¾	2½	330	900	300	130,000
Short-head cone	36	2⅞	⅛	½	15	50	75	22,500
(Intermediate)	48	3¼	⅛	½	20	100	150	45,000
(Rated by bottom	66	4⅜	3/16	½	65	175	200	88,000
diameter of head in inches)	74	5¼	3/16	½	120	300	300	143,000
Gyrosphere	24	3	⅜	1½	20	40	30	9,100
(Intermediate)	36	4½	½	1½	50	120	75	21,500
(Rated by bottom diameter of head in inches)	48	7	¾	1½	100	200	125	36,000
Newhouse	5	5	¼	1½	15	72	40	14,000
(Intermediate)	7	7	⅜	2	34	140	75	24,000
(Rated by width of	10	10	½	2½	54	260	125	49,000
inlet opening)	14	14	½	3	110	530	250	120,000

Where the product from the primary crusher goes to a screening and secondary crushing operation, the feed to the secondary crusher should be as constant as possible, and for this reason a storage pile beyond the primary crusher is desirable. From this surge pile a mechanical or vibrating feeder and belts deliver the crushed material at a uniform rate to succeeding operations. Separating the quarrying from secondary crushing and screening is also more economical.

This was demonstrated by actual experience when the Norris Dam plant was moved to Hiwassee Dam. A revised layout there by using an intermediate surge pile saved a great deal of operating expense and permitted all the secondary crushing and sand making to be housed in one building.

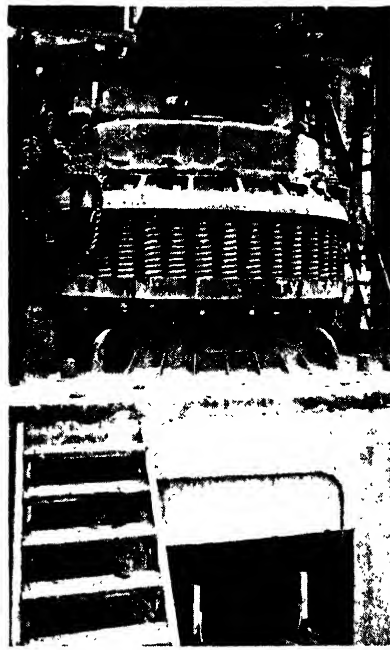


FIG. 96.—Secondary crusher (Symons) used to crush oversize primary crusher product.

The belt conveyor leading from the primary should be equipped with a magnet which removes metal, such as pieces of drill steel and bolts, which may damage the secondary machinery. Table 36 gives the principal data on some of the standard heavy crushers.

Secondary Crushers.—The secondary crusher for breaking down oversize rock is usually of the gyratory or cone type (Fig. 96), which has a high capacity for making fines. A modification of the cone type is obtainable with a spherical head, known as the Gyrosphere. A third type, known as a Newhouse (Fig. 97), has a direct-connected motor drive and crushing head. This type has capacities of 100 to 300 tons or more per hour. The motor shaft, running at 500 to 700 r.p.m., extends through the core of the mandrel and drives an eccentric bearing which imparts a high-speed gyratory oscillation to the mandrel. This unit is designed

for suspension from the building frame, thereby saving the cost of a concrete foundation.

In order to reduce the load on the secondary crusher it is standard practice to scalp out the acceptable sizes of crushed aggregate and deliver only the oversize to the secondary. Vibrating scalping screens for this class of service are very satisfactory.

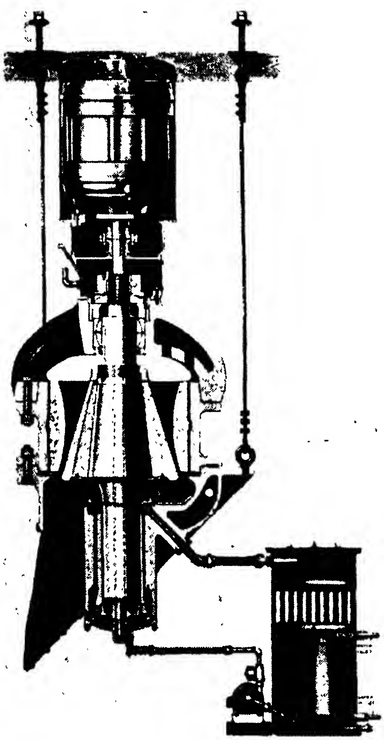


FIG. 97.—Cross-section of Newhouse secondary crusher.

Manufactured Sand.—Sand may be produced either by direct grinding, attrition grinding, or by impact grinding. The most important elements to be met in a sand-manufacturing process are sizes of the particles, gradation, shape, and cleanliness. These factors dictate special precautions in the selection of sand-making machinery, of which the following types of equipment are available:

1. Hammer mill, consisting of a high-speed rotating armature with suspended hammers which repeatedly strike the rock and throw it against breaker plates, thereby successively breaking the stone down to small particles (Fig. 98); the larger sizes of this equipment have capacities of 60 to 100 tons per hour.
2. Ring crusher. This is similar to the hammer mill except that in place of swinging hammers there are swinging annular rings.
3. Cone crusher of the Symons high capacity type with projecting shaft, similar to Fig. 96.
4. Gyrosphere, similar to cone with projecting shaft, but with a spherical head.
5. Bell-head gyratory crusher with suspended shaft.

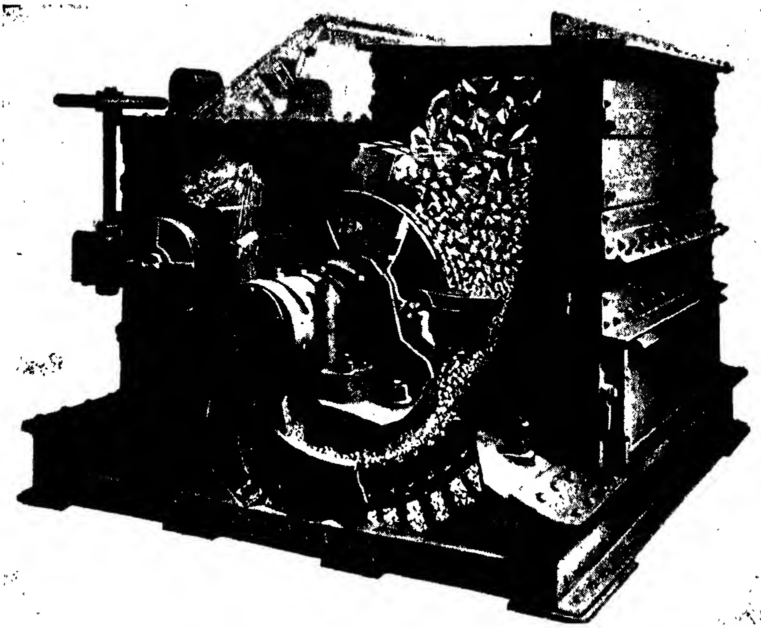


FIG. 98.—Cut-away view of hammer mill for reducing rock to small sizes and sand particles.

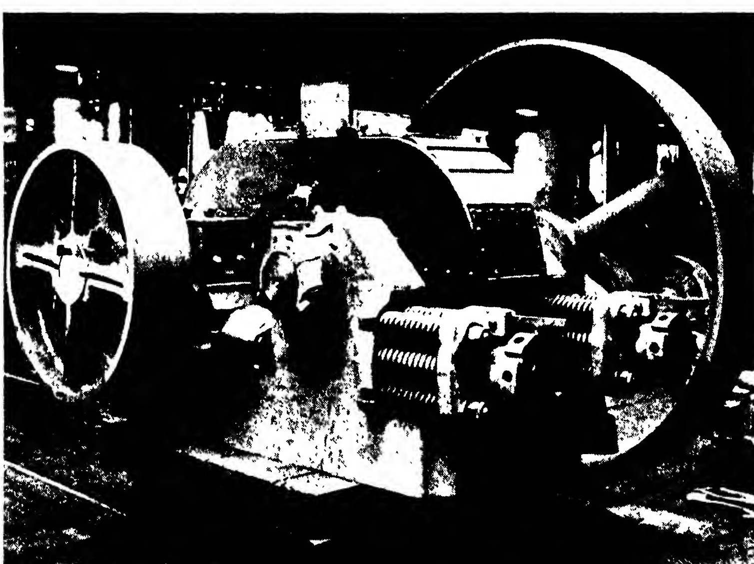


FIG. 99.—Crushing rolls for fine reduction of rock.

6. Roll crusher (Fig. 99), consisting of two steel cylinders rotating toward each other. The larger the pieces of rock in the feed, the larger must be the rolls.

7. Rod mill (Fig. 100), consisting of a horizontal revolving cylinder with a charge of steel rods which are constantly tumbling over each other, thereby crushing the rock. This type of equipment is suited only to special conditions. It produces a large amount of fines and is therefore useful where the natural

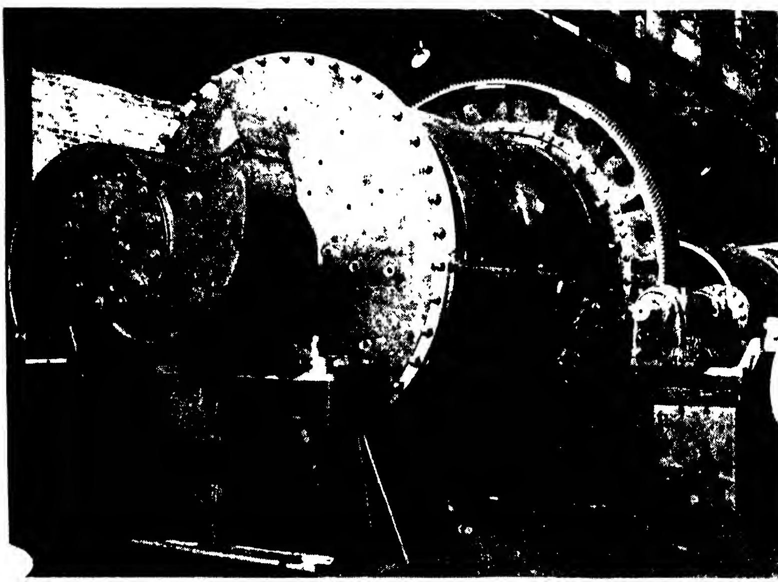


Fig. 100.—Rod mill for fine reduction of aggregates.

sand is deficient in fines, as was the case at Marshall Ford Dam, where a rod mill proved very useful. This mill, 5 ft. diameter by 10 ft. long, ran at 25 r.p.m. and required 100 hp. to convert the fineness modulus of the natural sand from 3.51 to 2.19 at the rate of 30 to 70 tons per hr. The size of the entering particles is limited to relatively small sizes such as sand which will allow the rods to tumble parallel to each other.

The sand plant at Norris Dam, designed by C. D. Riddle, is an outstanding example of a first-class sand-making installation. A great deal of time and study was devoted in advance to a proper selection of the equipment and methods for producing sand. The rock was a dolomite with from 2 to 6 per cent of silica. Par-

ticular study was given to the possible use of rolls, rod mills, hammer mills and modified gyratories. The screen analyses of the products from various types of experimental mills were all similar in that there was a surplus of 8- and 14-mesh, and a deficiency of 28-, 48-, and 100-mesh material. There was, however, a great difference in the shape of the particles. The hammer mill produced the best, a cubical shape; the gyratory gave a

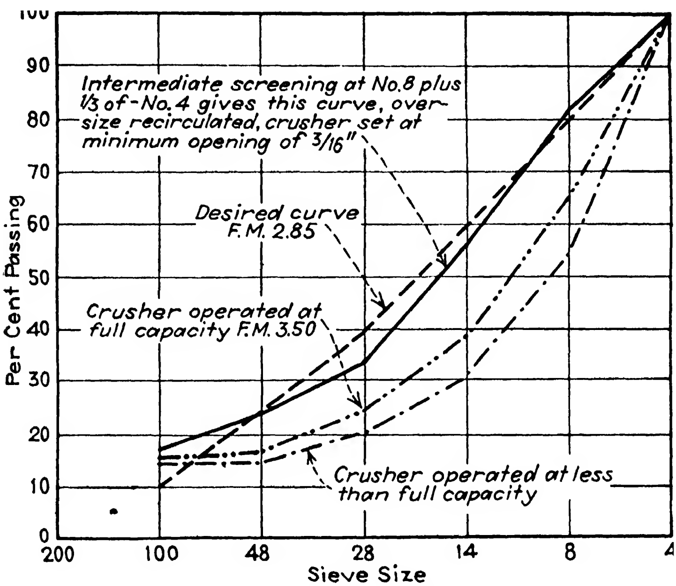


FIG. 101.—Gradation curves for dolomite sand produced by 3-ft. short-head cone crusher, showing effect of intermediate screening. Sieve analysis shows effect of varying load on crusher. Product through No. 4 screen, oversize material recirculated, crusher set at minimum opening of $\frac{3}{16}$ in. New feed is product from small jaw crusher, mostly -3-in. to $+\frac{3}{4}$-in. stone.

wedge, pyramidal, or flat shape; the rolls produced a splintery shape. It was also found that a modified gyratory crusher could produce a satisfactory product by employing a choke feed which developed the desired shape of product by attrition grinding. However, the setting of the discharge opening had to be larger than normal and produced considerable oversize for recirculation.

It is practically impossible to obtain the desired gradation directly from a sand-making machine, and it is therefore necessary to combine a very flexible screening arrangement with the sand-producing machinery. This is made clear in Fig. 101, which shows two types of products obtained under different conditions

of grinding, and a modified product which coincides more nearly with an ideal gradation curve. This product is obtained by screening out some of the intermediate sizes and returning them for further grinding. This method is called adjustment of gradation by selective screening and by regrinding of undesirable sizes and oversizes. Sometimes the circulating feed for such regrinding may be up to 200 per cent of the new feed entering the plant.

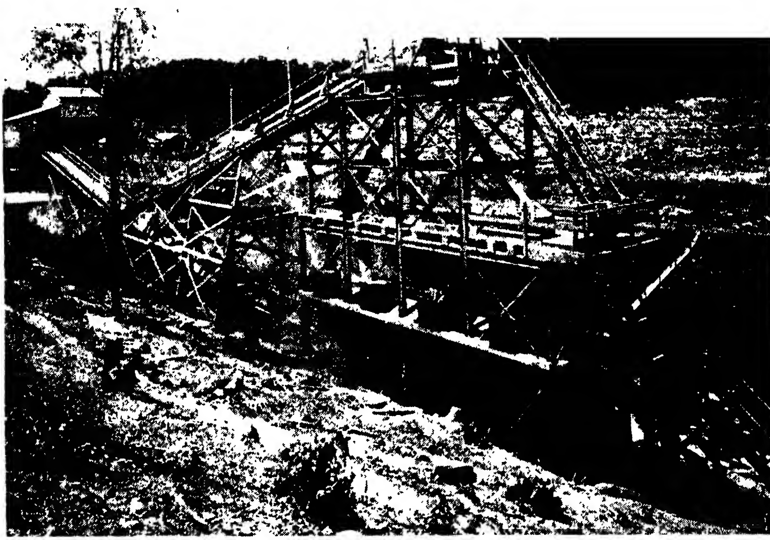


FIG. 102.—Sand-screening plant for dry selective screening. Surplus is returned to crushing mills in background.

Since it is difficult to screen the smaller sizes, a large amount of screen area is needed, and selective dry screening becomes quite a large operation (see Fig. 102).

From the standpoint of particle shape and its effect on the workability of concrete the hammer mill product was found most satisfactory. In comparison with the product from the gyratory crusher, from 4 to 5 per cent less cement was required to obtain the same workability. This great potential saving of cement on a large project justified the selection of somewhat more expensive grinding methods.

The following is a summary of the principal features of the Norris Dam sand plant:

Two Allis-Chalmers Pulverators, 42-in. grate-bar circle diameter by 48-in. effective length, direct-connected to 250-hp. slip-ring, 880-r.p.m. induction motors

Type of hammers: stirrup
Grate-bar spacing: 1¼ in.
Two Pennsylvania SXR-100 Thor Ajax hammer mills. Hammer circle 42 by 47 in. effective length, direct-connected to 250-hp. slip-ring, 880-r.p.m. induction motors
Adapted for stirrup-type hammers
Grate-bar spacing: 2 in.
Lower breaker plate and grate bars adjustable
Size of feed: passing 3-in. square hole
Size of usable product: passing ¼-in.
Operation: in closed circuit with double-deck screens
Screens: ¼-in. opening top deck, 0.093-in. opening lower deck. All stone retained on upper deck returned as circulating load together with approximately 40 per cent of stone retained on lower deck. Recirculating load amounted to 25–100 per cent of new feed
Total tonnage handled: 852,000
Average output in tons per hour: 121
Average motor load, hp.: 200
Tons per hp.-hr.: 0.314
Tons per hammer mill-hr.: 60.2
Hammer costs, cents per ton: 2.1
Hammer metal consumption, wear and discard, lb. per ton: 0.126
Average weight per hammer (*new*) lb.: 28.6
Average weight per hammer (*used*) lb.: 18.0
Output of Sand Plant:
  Coarse sand: −¼ in. to +No. 8, 26 per cent
  Fine sand: −No. 8 (originally split at No. 10), 58 per cent
  Waste: 16 per cent
Cost of rock fed to sand plant: 0.51 per ton
Cost of sand produced: $1.02 per ton

A detailed and valuable description of aggregate manufacture at Norris and Hiwassee Dams has been recorded by F. Cadena in *Transactions* of A.I.M.E. in 1938 and 1939.

Screening of Aggregates.—Sometimes very serious mistakes are made by specifying the tolerances for screening operations in such a way that no equipment can meet them. The forbidding of tolerances and expectation that no oversize or undersize will appear in a particular grade is, of course, unreasonable. It is considered acceptable, for example, in producing a ¾ to 1½-in. grade, to require not *more* than 5 or 10 per cent to be retained on the larger screen size, and not *less* than 85 or 90 per cent to be retained on the lower screen size, or an over-all tolerance of 20 per cent.

It is not important that the different sizes of sand or gravel be split exactly on the specified sizes of screen as long as their composition is consistent so that, upon recombining, there is obtained an acceptable gradation that will produce first-class concrete with a minimum of cement. Experience has shown that the larger sizes of stone within a grade are less likely to pass through the screen, thus tending to make the various grades deficient in top sizes. For example, at Norris Dam separations were desired at 6, 3, 1½, ¾ in. and No. 4, and screens having these openings were initially installed. However, experience showed that the desired separations of aggregate could be obtained more satisfactorily by changing the screens to the following sizes: 7¼, 3½, 1⅞, ⅞, and ⅜ in.

Four sizes of stone and two sizes of sand were produced at Norris Dam in the following average proportions, these being controlled by the characteristic fracture of the rock and the required design of the concrete mix: cobbles, 17 per cent; coarse rock, 12 per cent; medium rock, 14 per cent; fine rock, 15 per cent; sand, coarse and fine, 35.5 per cent; miscellaneous and loss, 6.5 per cent—total, 100 per cent.

Screens.—The revolving screen is one of the simplest types and usually has relatively long life. However, it is more suitable for smaller installations or in connection with large natural gravel-pit operations where the scalping out of large boulders is involved. Revolving screens for sizing have limitations because the large particles roll ahead, thus blocking the opening for the passing sizes, the material must be lifted high, which requires extra power, and a relatively small portion of the screen area is in contact with the rock at a given time.

Heavy-duty single- or multideck vibrating screens have now been developed for rock sizes up to 6 and 8 in. which, as a rule, are superior in operation, space requirements, and in screening efficiency.

Vibrating screens are obtainable in various types which are roughly classified as follows:

1. Shaker screens which have a relatively low amplitude of vibration and are of little use in rock-processing plants.

2. Electromagnetic screens for sand in which the screen cloth is flexed.

3. Electromagnetic screens with vibrating frames for sand and small stone.

4. Positive-throw eccentric vibrating screens mounted on springs. This type is most common and can readily handle large aggregate up to 6 and 8 in. Vibration is obtained by driving an eccentric cam or by the rotation of unbalanced weights.

Most vibrating screens are set at an angle to develop gravity flow of the material. Installations should provide for making field adjustments on the slope, throw of the eccentric, and the

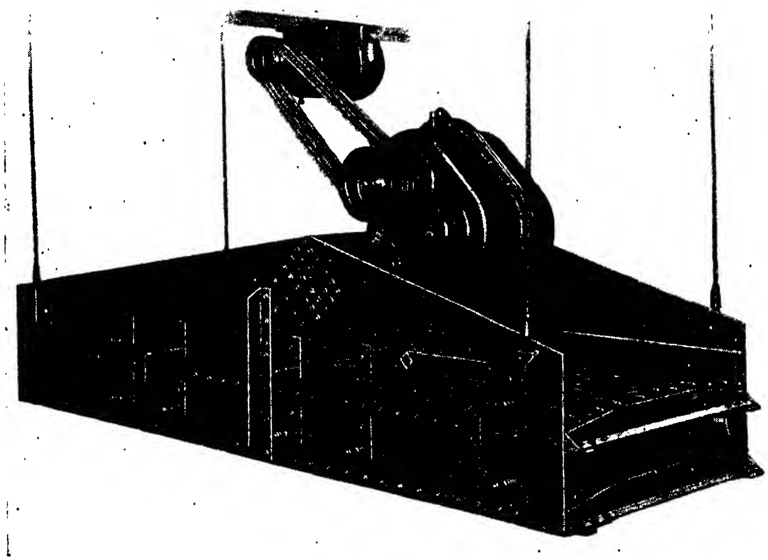


FIG. 103.—Horizontal-type double-deck vibrating screen.

direction of rotation either with or against the flow of the material. More recently horizontal screens (Fig. 103) have been developed with a forward vibratory motion which are very effective and efficient.

There is considerable variation of standard design among different screen manufacturers. In general the capacity of screens runs in approximately the following range:

Size of Opening in Screen	Tons per Hour per Square Foot of Screen Area
No. 14	½ to 1
No. 4	2 to 3
½ in.	4 to 6
¾ in.	4 to 6
1½ in.	5 to 7

Double-deck screens are used rather commonly. In some special cases triple-deck screens have been used satisfactorily. They are, however, less suitable for large crushing plants because of the greater difficulty in replacing screen cloth, reduced accessibility, and low efficiency of the bottom deck. The mechanism for making quick and secure screen-cloth replacements and adjustments in screen tension is of great importance on any vibrating screen.

Screen cloth is obtainable as either woven wire, bar screen, or punched plate. For ¼, ⅜, or ½ in., a screen with elongated openings is sometimes used and will handle about double the capacity of square openings. When purchasing screen cloth, it is important to specify the size of openings rather than the number of meshes per inch, because the diameter of the wire may vary considerably. As a rule, a heavy wire is desirable for longer life, although this reduces the effective open area. It should be kept in mind that No. 4 screen, the division point between sand and gravel, which is commonly considered ¼-in. size, has a standard dimension of 0.185 in. in the Tyler series.

There is a great variation in quality of screen cloth, as is indicated by experience at Norris Dam, where one ⅜-in. screen costing $12.10 passed 29,000 tons; a ¼-in. screen costing $17.30 passed 137,000 tons; and a ⅛-in. screen costing $17.40 passed 31,000 tons.

For ⅜-in. or smaller sizes wet screening is usually much more efficient and is almost necessary in any case where the fines contain enough moisture otherwise to plug the screen cloth. However, precautions should be taken in deciding on wet screening, particularly in sand-manufacturing plants because it may result in very much greater wear of crusher parts. Furthermore, wet screening may overload the classifiers, owing to excess water, or make the control of the water-cement ratio in the concrete mix more difficult. Wet screening also introduces freezing trouble. Where it is necessary to split the sand into sizes below a No. 8 screen, a hydraulic classifier process is the most effective.

A matter which is usually not given enough consideration in design of screening plants relates to proper arrangement of chutes. It may be a primary problem, rather than a mere detail to arrange the chutes so that maintenance on them is reduced to a minimum. Manganese liners and rubber liners are helpful, but wherever

possible pockets should be provided which retain some of the stone or gravel to absorb the impact of the falling material. As an indication of the problem it is easy to calculate that in a screening plant which is designed to produce 2,000,000 tons of aggregates a gravity fall of 50 ft. from screen to screen and through chutes down to hammer mills or other processing equipment results in the generation of 100,000 hp.-hr. of energy, and this energy is absorbed primarily in wear of equipment, chutes or chute liners, in breakage of material due to impact on itself, and in noise and vibration.

Washing of Aggregates.—For primary washing of aggregate up to 6 or 8 in. in size and containing considerable clay, special scrubbers are used. These are large revolving cylinders with vanes and paddles which lift and tumble the gravel over itself in a bath of water. Another type for washing stone and gravel is the log washer which operates as a screw washer does for sand. Further effective means of washing the aggregates as they go through a screening plant may be obtained by directing sprays or jets of water on the aggregate as it flows over the screens. An important point here is that high pressure is less effective in washing the aggregate as compared with greater volume at lower pressure.

There are various types of sand-washing and classifying equipment available including the following: drags of the reciprocating type or with a continuous chain; hydraulic-vortex classifiers; rotating-vane classifiers; dewatering scoops; and cone settling tanks. Settling tanks and drags have capacities up to 24 and 48 tons per hour, and use from 550 to 1,150 gal. of water per minute. The water required for washing a ton of sand per hour is approximately 10 to 20 gal. per min.

In some cases there is danger of washing out too many fines, particularly in the sizes between No. 50 to 100 mesh, and also in the 100 to 200 mesh, a size which is of considerable importance in making good concrete. At Norris Dam a substantial saving was obtained by collecting in a cone reclaimer a large part of the fines which were washed out of the sand classifier; these were recombined with the sand being processed. The Norris concrete sand contained up to 13 per cent of passing 100 and, contrary to usual practice this proved to be a desirable feature. The use of this sand containing a higher percentage of fines resulted in a

reduction of cement requirements in the concrete, as well as utilizing more of the processed materials which had the same value per ton as sand. In nine months the total gross saving was $42,000, or $35,000 net.

Another problem in collecting fines relates to the handling of dust, particularly where a high silica content may expose the workers in the plant to silicosis. An effective dust-collecting system under such conditions is of utmost importance.

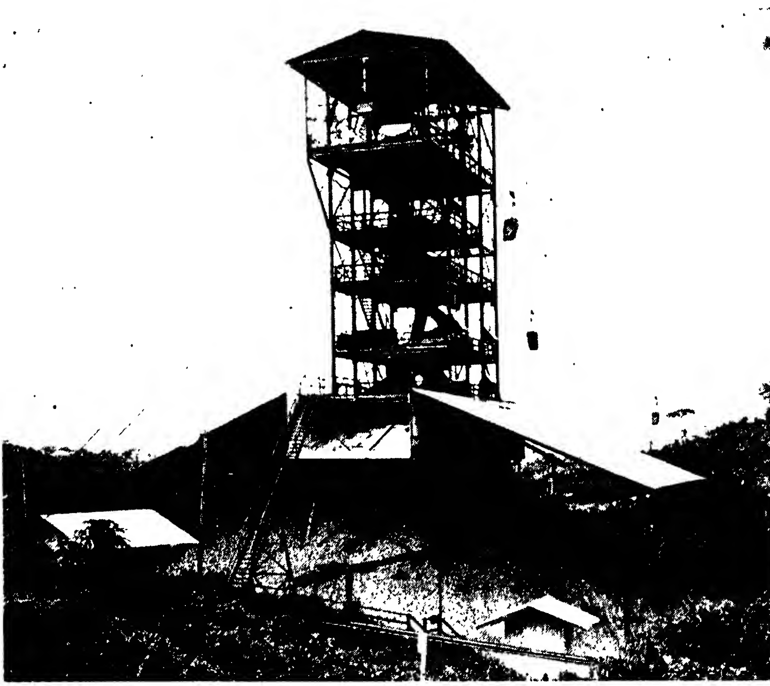


FIG. 104.—Vertical type of screening plant used at Madden Dam.

Storage of Aggregates.—An important element of a plant for a large dam is the storage of aggregate in sufficient quantity to meet effectively the demand of the concrete-mixing and placing equipment. Some of the most characteristic types of storage are shown in an accompanying illustration. The vertical system of screening and storage directly below the screening plant was used at Madden Dam (see Fig. 104). Here the raw aggregates arrived at the top over an aerial tramway and dropped through the various sizing screens to storage piles directly below. Timber-

lined walls separated the different sizes, and finished sizes were drawn from storage by a belt conveyor in the underground tunnel.

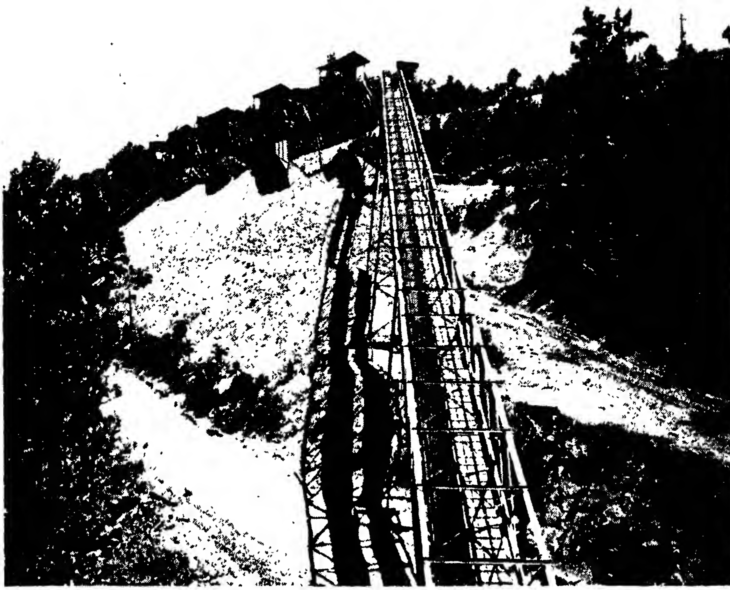


FIG. 105.—Horizontal type of screening plant and storage at Norris Dam.

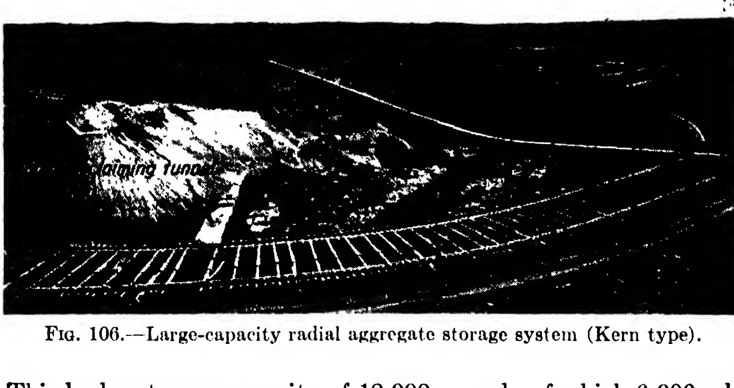


FIG. 106.—Large-capacity radial aggregate storage system (Kern type).

This had a storage capacity of 18,000 cu. yd., of which 6,000 yd. was live storage. The horizontal screening-plant layout as used at Norris Dam (Fig. 105) provided storage piles under the

screening structure which contained 65,000 tons of gross storage; 16,000 tons of this was live storage. A reclaiming tunnel was located under the full length of the storage pile.

At Pickwick Landing Dam the Kern circular storage system (Fig. 106), with a capacity of 300,000 tons, proved effective and economical because the aggregates were produced under contract by a large and expensive floating dredge and barge transporting plant. By storing the finished aggregate as fast as the dredge could produce it, instead of limiting production to the rate

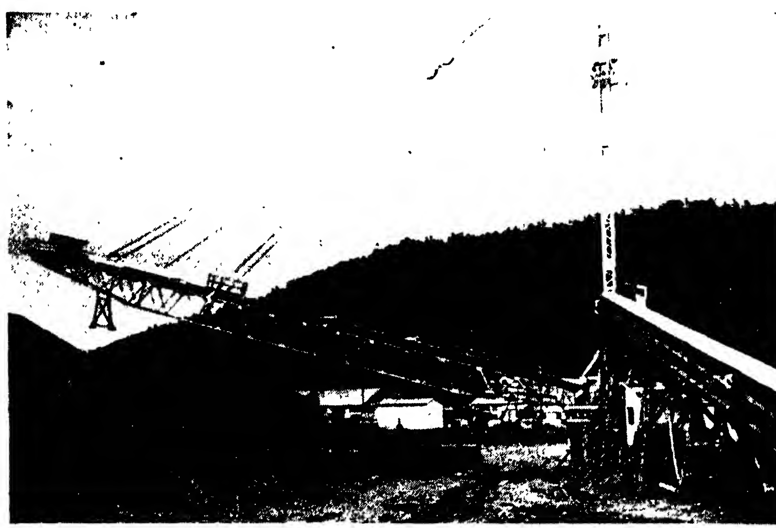


FIG. 107.—Radial stacker boom for storing aggregates. Boom carries reversible belt, and aggregates can be reloaded at tip of boom for delivery to mixers out of storage.

required by the mixing plant, the cost of the aggregate was reduced sufficiently to pay for the entire storage system. At the same time once the aggregate was in storage it was always available for concreting, and this eliminated possible shutdowns of the concrete plant due to delays in the gravel production plant. The operating scheme consisted of the delivery of aggregates on a belt conveyor to a central tower where a rotating spout directed the various sizes into the proper radial bays around the tower. As the bays filled up, the gravel was drawn out radially into the storage pile by a drag scraper operated from a traveling tower which ran on a track surrounding the storage area. By reversing

the drag scraper, gravel was drawn back to the tower and discharged through a gate into a collecting hopper and onto the reclaiming belt which carried it to the mixing plant.

A modification of the circular storage was employed at Guntersville Dam where aggregates were produced from the river bed by a suction dredge and delivered to the dam in barges. The problem here was to store up to 215,000 tons of finished aggregate which was delivered to storage at a greater rate than needed for

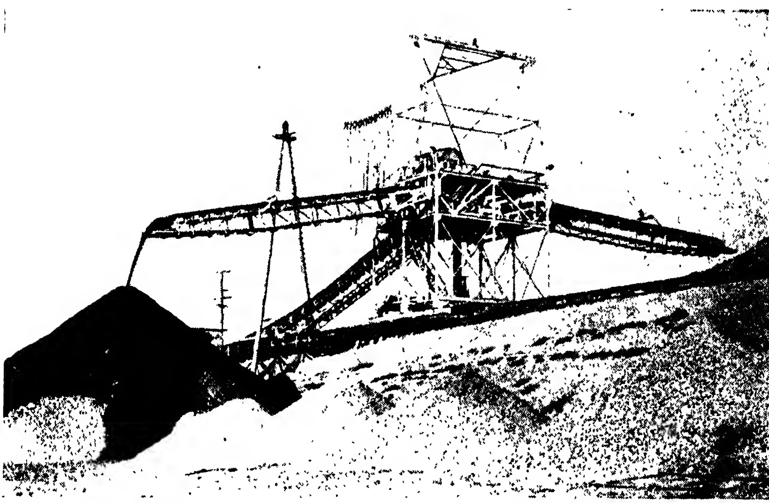


FIG. 108.—Airplane type of traveling stacker to store aggregates. Reclaiming tunnels are located under each pile.

concreting. For this purpose, a novel layout was devised (Fig. 107) which consisted of a central tower and guy derrick mast which supported a long stacker boom. This boom could be rotated and elevated by a derrick hoist and it could be spotted over the various piles of sized aggregate for delivering aggregates to storage. A conveyor ran from the base of the boom to the mixing plant to deliver aggregates direct from barges, or, from storage by loading into a hopper at the tip of the boom and reversing the boom conveyor belt.

An airplane type of stacker (Fig. 108) was used at Grand Coulee Dam to build up two long and very large storage piles having a total capacity of 148,000 tons, of which 77,000 tons was live storage. Reclaiming tunnels under each pile were

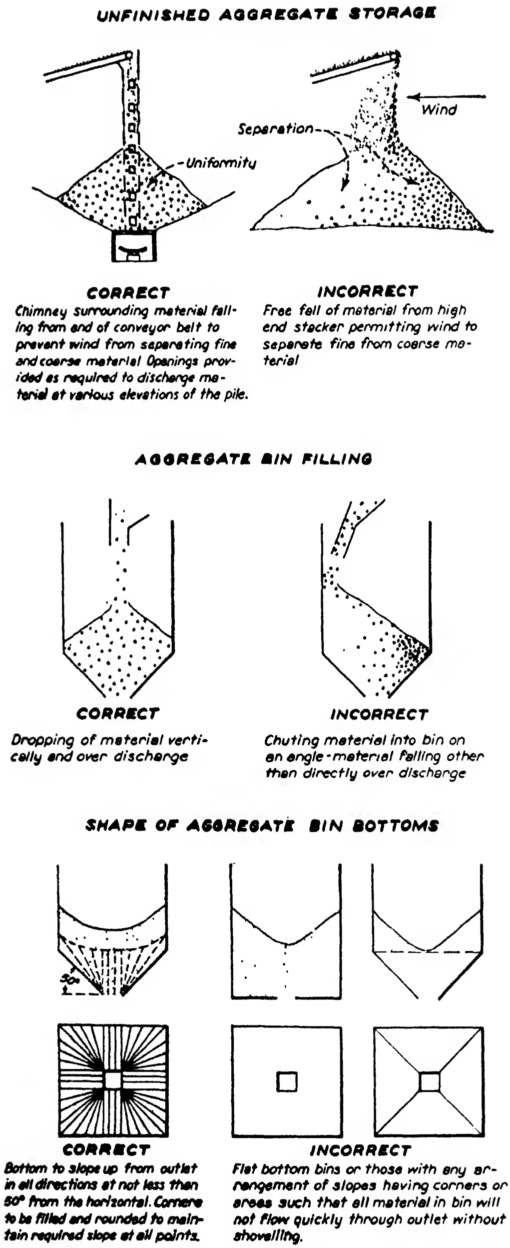


FIG. 109.—Diagrams showing methods of storing aggregates to minimize segregation. (*By Lewis E. Tuthill.*)

equipped with gates and belt conveyors by which the aggregate was drawn off and delivered to the mixing plant.

At Bonneville Dam aggregate was stored in octagonal timber silos 30 ft. inside diameter by 57 ft. high, containing 1,600 cu. yd. in each silo. They were built up by stacking 6-in. thick timbers, which were 16 in. wide at the base of the silo and varied to 10-in. widths at the top.

Another aggregate system of considerable interest was used at Fort Peck Dam, where the screening plant itself traveled

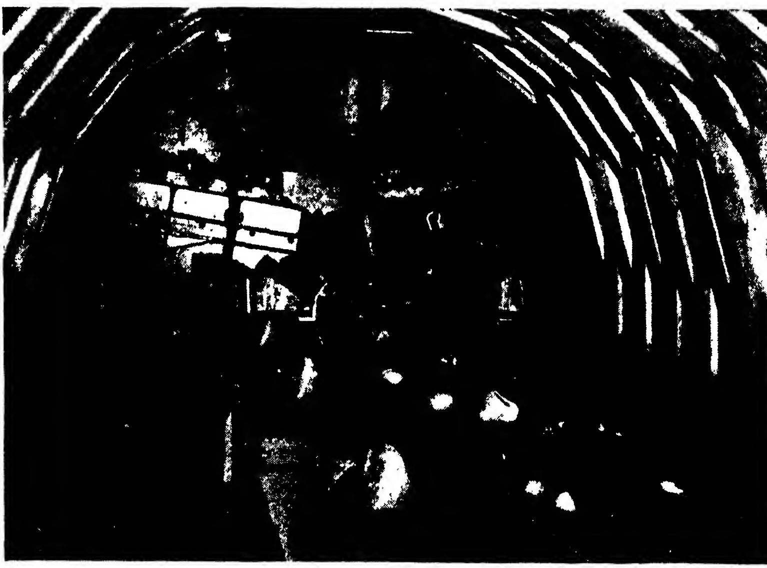


FIG. 110. Magnetic vibrating feeders delivering aggregates from storage to conveyor. Note tunnel formed by timber segments.

along in the borrow pit and loaded the final product directly into long strings of railroad cars which, in effect, were the storage element. The rejected materials, consisting of oversize and undersize, were in this case loaded back into the abandoned section of the borrow pit.

In designing storage systems, adequate means, such as rock ladders, should be provided to minimize breakage and segregation. Figure 109 shows some suggestions for handling aggregates to minimize segregation. Drainage is a major item, particularly in the storage of sand. A constant moisture content offers the simplest means of maintaining proper control over the

concrete mix. In some cases special roofs of timber, sheet metal, or canvas are desirable to protect against rain and keep it from accumulating in the craters above the reclaiming tunnel. Another important factor is that some types of sand tend to pack together in storage, thus requiring special handling to get the sand to flow into a collecting tunnel below.

Reclaiming Tunnels.—Reclaiming tunnels are sometimes a major item of expense. Concrete tunnels are particularly expensive. At Grand Coulee Dam a laminated timber tunnel was developed and used with considerable success (Fig. 110). The roof was arched and made up of eight or nine precut pieces of 4- by 10-in. lumber, cut and drilled for spiking at the mill. Such a tunnel costs about $16 per lineal foot for lumber and erection, which is about half the cost of a concrete tunnel.

CHAPTER XXI

CEMENT HANDLING

For large construction operations cement is now almost invariably delivered in bulk, either in special hopper-bottom

FIG. 111.—Hopper-bottom cement cars connected to underground pumps which blow cement into overhead silo.

cement cars of the covered gondola type or in box cars carrying about 245 bbl. per car. Hopper cars (Fig. 111) are most satisfactory because they provide a very simple and cheap means for unloading, and do not require men and special equipment

to be located in the dusty atmosphere which is found in box cars. Cement hopper cars are available only in limited numbers in the northeastern part of the United States, and until they are more generally available it will be necessary on certain jobs to continue using the more expensive methods of unloading from box cars. The use of air-activated cement containers of the self-unloading type, transported on cars or barges, is developing in New York and vicinity. The containers have a capacity of 50 to 60 bbl. of cement.

The car-unloading methods listed in Table 37 are used in modern practice.

TABLE 37.—CAR-UNLOADING METHODS

Type of car	Unloading method	Transporting method to storage	Special features
Box cars	Scoop pulled by cable, guided by hand, pushing cement into a hopper alongside car door	1. Screw conveyor	For short horizontal distance
		2. Bucket elevator	For vertical conveying
	Portable unloader pumping direct into a silo or into a hopper feeding a bucket elevator	3. Fuller-Kinyon pump	For lift and distance
		4. Robinson conveyor	For lift and distance
		5. Fluxo conveyor	For great distance
Covered hopper cars	Gravity feed directly into transporting method 1, 2, 3, 4, or 5		More simple and economical than box cars
Gondolas with 5 or 6 containers	Steel containers, each holding 50 to 60 bbl. of bulk cement, equipped with compressed air aerators and connection to discharge hose through which cement is conveyed direct to silo.		Self-unloading from car to silo. Containers are separately portable.

Box cars require special timber bulkheads to confine the cement and keep it clear of the car doors. Where the cement is

unloaded by scraper scoops into a hopper located alongside the car the bulkheads are usually set on the inside parallel to the car doors, whereas with a portable unloader it is better to install the bulkheads at the cement mill to span the width of the car, so that upon opening the cars there is a section of open floor space on which to set the unloader. A removable board at the base of the bulkhead provides a simple means for drawing out the cement until the bulkhead is clear and can be removed.

Where the unloading of cars is intermittent it is generally desirable to feed directly into a silo of considerable capacity so that the transporting system to the point of use is made independent of the unloading system, thereby raising the output and efficiency of both systems. Steel silos with steeply sloping cone bottoms (60 degrees from horizontal) are most satisfactory and have largely displaced wood stave silos or sheds.

For certain operations on a large job it is necessary to have a supply of cement in bags so that it can be readily transported to special points of use, such as grouting operations in treating the foundations.

At Madden Dam cement was delivered from the United States to the Panama Canal Zone in paper bags built up of five plies with one ply specially treated with paraffin to keep out moisture during transit. From the ships the bags were loaded into box cars and delivered to a siding near the dam site. Here the bags were unloaded manually on to a belt conveyor which ran to a special chute equipped with steel knives. In dropping through the chute the paper bags were cut on all sides and landed in a revolving screen which thoroughly shook out the cement and dropped it into a collecting hopper. A Fuller-Kinyon pump located below this hopper delivered the cement into a steel silo with a capacity of 6,000 bbl. The proper scheduling of cement deliveries for such an operation is of considerable importance, and in the case of Madden Dam was carried out very effectively.

Cement Conveyors and Pumps.—The bucket elevator for raising cement into a silo is one of the cheapest methods and was employed on the Chickamauga and Guntersville projects (Fig. 112) because it was possible to bring the railroad cars directly to the base of the silo. A portable unloader with a capacity of 175 bbl. per hour delivered the cement into a hopper from which the bucket elevator raised the cement into the silo

or directly into the mixing plant. The elevator, rated at 160 bbl. per hour, was 103 ft. high and was composed of buckets with a capacity of 0.33 cu. ft. each, which traveled 120 ft. per minute and were driven by a 25-hp. motor. The entire unit was inclosed in a housing and weatherproofed. The average actual performance of this elevator was 89 bbl. per hour of gross time, or 121 bbl. per hour of net running time. A steel silo adjacent to the mixing plant had a capacity of 4,000 bbl. Normally, as

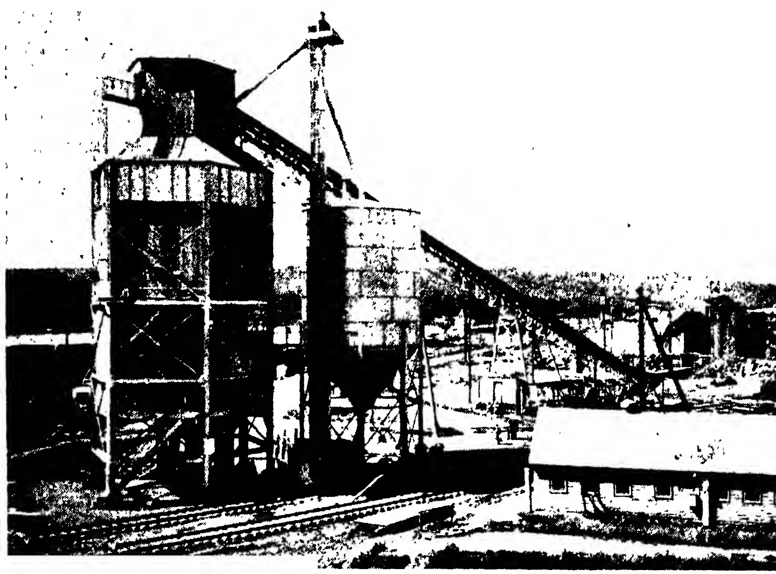


FIG. 112.—Vertical bucket elevator delivering cement to mixing plant or to 4,000-bbl. storage silo.

much cement as possible was elevated directly into the mixing plant, and only about 15 per cent of the total cement went through the silo as reserve storage. Approximately 11 cars per day were unloaded, at a rate of 1.75 hr. per car. The bucket elevator had a relatively low repair cost; unloading cost for operation and equipment depreciation was 7cts. per barrel.

Inclined belt conveyors have been used on some jobs in the past, but such methods are now considered obsolete. For certain special cases a vertical screw conveyor has been developed. Such a screw is housed in a steel tube, has a flat pitch angle, and runs at sufficiently high speed to deflect the cement upward.

The Fuller-Kinyon pump consists essentially of an electric motor driving a heavy-duty screw within a steel housing, the screw feeding the cement forward into an aeration chamber where air is supplied at a pressure of 30, 40, or 50 lb. per sq. in., depending upon the duty of the pump. This equipment aerates the cement just enough to make it "fluffy" and furnishes the necessary pressure for propelling it forward through a steel pipe usually from 4 to 6 in. in diameter. These pumps are available for

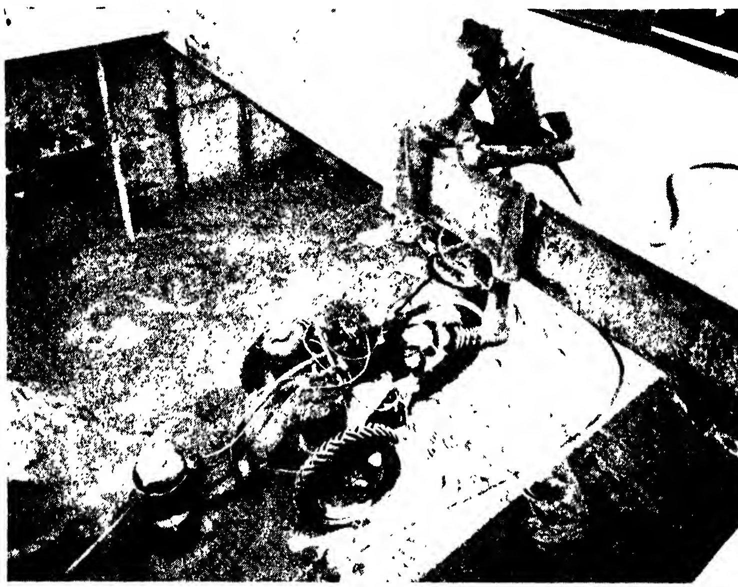


Fig. 113.—Portable type of cement unloader for barges or box cars, with remote-control operation. Capacity 175 bbl. per hr. with 40-hp. pump.

stationary mounting, as under hoppers or connection to hopper-bottom cars, or as portable unloaders equipped with a special pickup feeder and mounted on wheels for "sweeping up" bulk cement in box cars or barges. A flexible hose connects the unloader to the main transport line. Portable unloaders are made in capacities of 10, 20, 30, and 40 hp., using 3- to 5-in.-diameter transport lines, the size depending on length, capacity, and general layout. Large automatic remote-control portable unloaders are made in 100- and 150-hp. sizes which carry cement at a rate of 550 bbl. per hr. and convey it a distance of 550 ft. or more with a vertical lift of 130 ft. Stationary pumps are

available in sizes from 4 to 10 in. for transport lines ranging from 2½ to 12 in. in diameter.

At Pickwick Landing Dam the cement was received in steel barges having a capacity of 1,500 bbl. each and was unloaded by a 5-in. portable unloader, rated at 100 bbl. per hour, and a 6-in. unloader handling 149 bbl. per hour. These unloaders were driven by 40-hp. motors. The 6-in. pump used about 357 cu. ft. per min. of air, delivering cement a distance of 330 ft.

A 5-in. stationary pump was employed at Morris Dam, Pasadena, Calif., to transmit cement through 730 ft. of line sloping upward with a rise of 302 ft. This is one of the record installations on construction work, and delivered cement at a rate of about 125 bbl. per hour. Pumping distances of 3,600 ft. have been reported with this type of equipment.

The automatic remote-control unloader (Fig. 113) is a new development which permits the operator to stand at an advantageous position without getting into the dusty part of a car. The movements and direction of travel of the unloader are controlled entirely through an electric cable. When the feed is too great, the feeder automatically stops but cement pumping is continued, and the operator can then draw back the unloader and reduce the load to a point where it will operate satisfactorily.

The air requirements for a cement-handling system run approximately as shown in Table 38 (the pressures ranging from 30 to 50 lb. per sq. in.).

TABLE 38.—AIR REQUIREMENTS FOR CEMENT-HANDLING SYSTEM

Pumping distance, ft.	Cu. ft. of air per bbl. of cement	Cu. ft. of air per min. for each 100 bbl. of cement per hr.
250	75	120
500	100	180
750	125	220
1,000	155	280
1,500	200	340
2,000	240	390

In the Robinson system the cement is drawn off from a silo, hopper, or direct from hopper cars into a steel aeration tank with a capacity of approximately 50 bbl. When the tank is filled, air is injected through a special arrangement of pipes, and

the aerated cement is directed into a collecting horn connected to the pipe line through which it is transmitted to the desired storage points. A typical operation required about 10 sec. to fill the tank, and 50 sec. to charge it with air. Once the tank is completely charged, the discharge line is opened and the cement blown out into the transport line, which requires about 5 min., or a total cycle of 6 min.

The Robinson system (Fig. 114) was at one time operated manually, particularly in the manipulation of valves, but

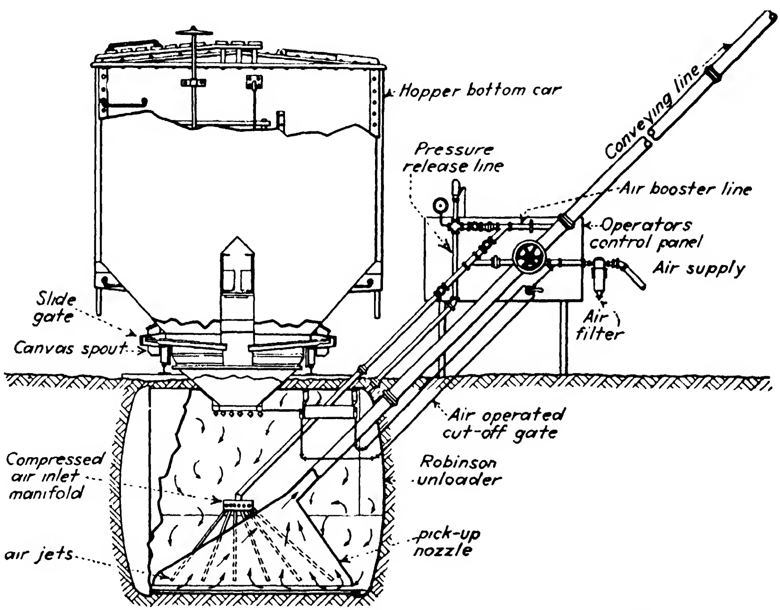


FIG. 114.—Diagram of Robinson cement-conveying system.

the conveyor can be made automatic through the use of electric relays and air valves. A 550-ft. length of line with a rise of 110 ft. can handle about 200 bbl. per hr. This system can be used with 4-in. lines up to 1,500 ft.; with 5-in. lines distances up to 3,000 ft. are claimed. At Pickwick Landing Dam, cement was transmitted a distance of 1,200 ft. from the storage silo to the mixer plant. For this installation two tanks, each 6 ft. in diameter by 7 ft. long, were used, one operator handling both tanks. The filling and discharging for one tank were done at the rate of 10 shots per hour, handling 200 to 240 bbl. per hr., and with two tanks 12 to 13 shots per hr., handling 240 to 290 bbl.

per hr. The second tank served primarily as a standby. In the event of pipe plugs, it has been found possible at Pickwick to release such plugging without the need of removing the line by applying pressure and making a sudden release which has a tendency to pull the cement down and in that manner break up the plugs. The line is normally kept blown out and empty when not in use.

The differences between the Fuller-Kinyon system and the Robinson system are chiefly in that the former has a motor-driven rotating element and requires a constant supply of air at from 30 to 50 lb. (sometimes 15 to 20 lb.), while the latter has few moving parts and requires an intermittent supply of air at about 30 to 80 lb. pressure, depending on the length of conveying pipe.

It is very important that air used for transporting cement be as dry as possible, and for this reason an aftercooler and moisture trap should be employed. Only the usual standard devices for drying air are needed to make it satisfactory for cement handling. The discharge end of a cement-transport line demands special consideration. Suitable dust separators are essential so that a minimum of cement is carried out by the exhaust air. This is extremely important and if not properly designed will lead to a substantial loss of cement. Certain so-called "simple" but makeshift devices have not always been found satisfactory. For large plants the dust separators should be of first-class proved design with means for cleaning them periodically.

For certain special conditions of long-distance and high-capacity conveying of bulk cement, as was needed on the Hoover and Grand Coulee dam projects, the Fluxo system has been successfully used. At Hoover Dam cement was pumped 5,420 ft. through 9-in. pipe at rates up to 550 bbl. per hr. The average rate was more nearly 450 bbl. per hour, which required 2,000 cu. ft. per min. of air at 90 lb. pressure. A 2-in. air line ran parallel to the transport line and tapped into it every 200 ft., with a valve in each tap to assist in blowing out cement in the event of a plugged line.

The same equipment was later transferred to Grand Coulee Dam and set up initially to pump 600 bbl. per hr. through 2,000 ft. of 11-in. pipe. After a second mixer plant was installed the total pumping distance to it was 6,200 ft. The transport

line discharged into special expansion tanks in which the cement was separated from the air and drawn off into the mixing-plant bins.

The Fluxo pump consisted of two 50-bbl. tanks. The tanks are alternately filled by gravity from an overhead bin and discharge alternately to maintain a reasonably steady flow in the

FIG. 115.—Aluminum tank for hauling cement 5 miles at Norris Dam. Front end of tank raised by overhead hoist in shed for dumping. Cement pump located below ground level.

transport line. The cement is thoroughly aerated within the tank and then forced into the line by air pressure. Control of filling and discharge valves is automatic through electric relays. Smaller Fluxo pumps are available for lower capacity installations and pumping distances of 1,500 to 4,000 ft.

Cement Haulage by Trucks.—The trucking of cement is generally handled in special types of truck bodies as shown in (Fig. 115), either of the round type as used at Norris Dam, (capacity 60 bbl.), or in the form of hoppers as employed on the Colorado River Aqueduct, so that the cement can be drawn directly into underground hoppers without special dumping or body-lifting devices. For the 13-mile run from the railroad siding to the site of the Madden Dam, standard rear-dump trucks

were employed with steel bodies of special type made exceptionally light but heavy enough to carry cement and having a capacity of about 60 bbl. These bodies had watertight covers equipped with filling holes. The covers could be removed when it was desired to convert the bodies to other service, but this feature did not prove advantageous, because of difficulties in keeping the body watertight. Unless only a small quantity of cement is to be handled, it is better to design a cement body for one particular purpose.

CHAPTER XXII

CONCRETE-MIXING AND TRANSFER EQUIPMENT

It is almost standard practice now to use structural steel in building mixing plants for construction jobs. Such plants are designed for vertical flow of aggregates from storage bins at the top through aggregate batchers, and from there to the mixers. The modern specifications for concrete on large jobs generally require four separate sizes of coarse aggregate, one or sometimes two sizes of sand, besides cement, thus making 6 or 7 different materials which must be stored in the bin compartments. Typical proportions of material to produce one yard of concrete are as follows:

TABLE 39.—MATERIALS IN A CUBIC YARD OF CONCRETE

Material	For mass concrete, pounds	For reinforced walls, pounds
Sand	865	1,150
$\frac{1}{4}$ to $\frac{3}{4}$ in.	500	975
$\frac{3}{4}$ to $1\frac{1}{2}$ in.	560	975
$1\frac{1}{2}$ to 3 in.	685	
3 to 6 in.	945	
Cement	395	520
Water	237	280
Total	4,180	3,900
Barrels of cement per cubic yard	1.05	1.36
Water-cement ratio by weight	0.60	0.53
Slump	2 in.	4 to 6 in.

For rapid batching this elaborate proportioning led to the use of individual batchers so that the different materials could be batched almost simultaneously, with the further innovation (for plants with three or four mixers) of a collecting hopper below the batchers feeding a revolving discharge chute to direct the aggregates to each mixer in sequence. The mixers are set

radially and discharge into a common central opening to the concrete-transporting means below. This type of plant was devised by C. S. Johnson, and the first one was installed at Madden Dam (Fig. 116) from designs made by the contractor's engineers. Since that time it has been used on other important projects, including Norris, Pickwick, Chickamauga, Fort Peck, Tygart, Hiwassee, Marshall Ford, Shasta, and Grand Coulee dams.

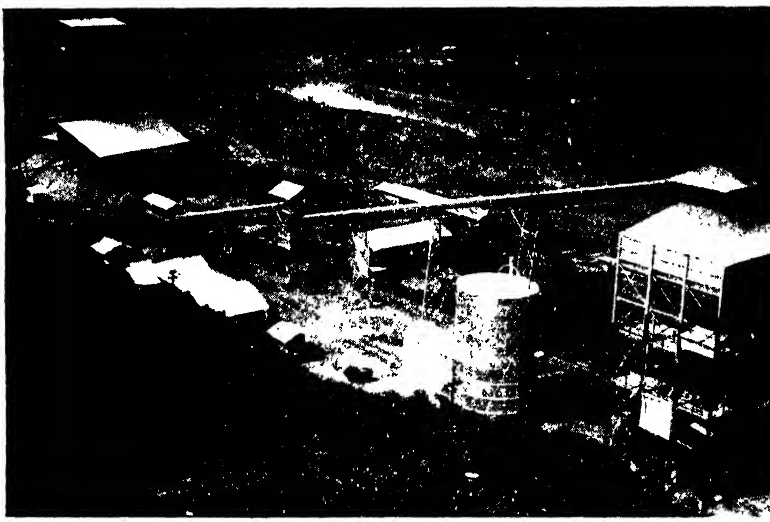


FIG. 116.—Structural-steel mixing plant used at Madden, Norris, and other dams. Cement delivered by trucks to silo at left.

An important feature at the base of a mixing plant is the wash-out pit into which the wash water used to clean the mixers, as well as condemned batches, may be dumped and flushed away through a large culvert drain. The foundation layout should also provide for an independent base for the mixers or spring mountings for them, in order to cut down vibrations in the building, which may destroy the accuracy of the weighing equipment.

Before a mixing plant can be designed it is necessary to determine the required size and number of mixers—in other words, the expected output of the plant, both actual and theoretical. This must be based, in part, on factors outside the plant which have a major bearing on the over-all economics of the construction program, such as:

1. Economic rate of supplying aggregates.
2. Best adapted concrete-placing plant.
3. Limitations in speed of construction due to nature of the structure.
4. Completion date required by the contract.

These points will be discussed in further detail in Chap. XXIII.

The size of the mixers generally depends on the capacity of the concrete-placing buckets and transporting system in the placing plant, as follows:

SIZES OF BUCKETS AND MIXERS

Capacity of Buckets, Cubic Yards	Size of Mixers Cubic Yards
1	1 or 2
2	1 or 2
3	2 or 3
4	2 or 4
6	2 or 3
8	2 or 4

Where the size of the mixer has an odd mathematical relationship to the size of placing buckets, an intermediate surge hopper is necessary from which the buckets are filled. All mixers in a plant should be of the same size. On a large job the installation of a spare mixer may be justified, especially where the plant is laid out to accommodate an extra unit without difficulty. Very often the efficiency of concrete placing improves, or conditions change, as the job progresses, and the installation of an extra mixer may eliminate a bottleneck in the operations, with profitable results.

Having defined the required monthly output (*actual*) of a concrete plant, the *average* daily output is readily obtained by dividing by 25 working days. This *average* output usually runs about 60 to 70 per cent of the *theoretical* output for which the mixing plant should be designed. The theoretical output represents plant *ability*, and must coincide with computed output based on individual cycles. For example, a 2-yd. mixer with a 3-min. cycle (2 min. mixing and 1 min. charging and dumping) will theoretically produce 20 batches or 40 cu. yd. per hr., or 880 cu. yd. in 22 hr. This output may actually be attained on occasional days when everything is going perfectly, but the *average* for a month of 25 days will more likely be 575 cu. yd. per day.

TABLE 40.—MIXER-PLANT OUTPUT

Project	Number of mixers in plant	Capacity of mixers, cu. yd.	Batch cycle time per mixer	Theoretical output, cu. yd. per hr.	Best actual output, cu. yd.		
					Per hr.	Per 24 hr.	Per month
Madden	3	2	3 min. 0 sec.	120	141	2,897	60,516
Norris	3	3	2 min. 51 sec.	180	181	4,090	92,780
Tygart	4	3	2 min. 45 sec.	240	274	5,679	125,445
Chickamauga	2	2	2 min. 23 sec.	100	102.5	2,364	45,798
Wheeler	1	2	2 min. 8½ sec.	50	54	1,000	25,600
Pickwick	3	2	2 min. 15 sec.	150	140	2,800	53,400
Guntersville	2	2	2 min. 18 sec.	100	104	2,081	39,706
Grand Coulee (1)	4	4	2 min. 30 sec.	384	382	9,170	221,615*
Grand Coulee (2)	4	4	2 min. 15 sec.	425	430	10,342	254,783*

* From one plant. Job output about twice as great from two plants.

Table 40 gives representative plant installations and outputs from actual experience.

Batchers.—One of the most important considerations in laying out a batching system is to provide easy means for changing the mix and for making whatever adjustments may be required by the concrete inspector. Such changes should be made without introducing delay in the normal functioning of the plant. Convenience in making such adjustments prevents misunderstanding and carelessness. When changing from one class of concrete to

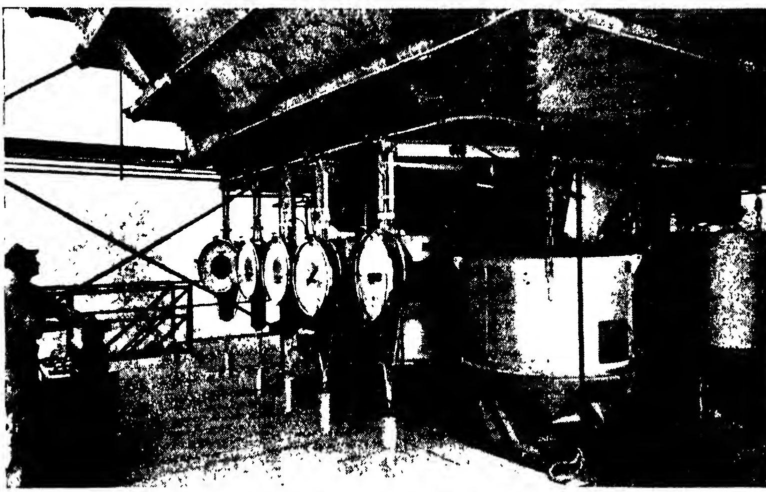


Fig. 117.—Battery of individual batchers and dial scales for weighing aggregates. Remote-controlled weighing and discharging.

another, adjustments must usually be made on the water, cement, and all aggregate batchers, and in compensating for moisture in the sand.

In the selection of batchers the multiple type is quite satisfactory for small plants where the amount of concrete to be mixed is not very great and the hourly output is relatively low—around 50 or 60 cu. yd. per hr. Batching plants for small jobs, consisting of steel bins, multiple weigh batcher, and cement bulking system have become well standardized and are now available from several manufacturers.

For mixing plants with three or four mixers the individual batchers are indispensable because of adjustments that can be made in the various quantities being weighed out and in changing from one class of concrete to another, of which there are generally

four and sometimes five kinds. Individual batchers can be operated by direct lever control, and this is preferred because of its greater simplicity for plants producing around 75 to 125 cu. yd. per hr. At Norris Dam (Fig. 117) the plant was designed for a capacity of 180 yd. per hour, and here manual air valves were used in the manipulation of all filling gates and discharge gates, the control being centered at two stands from which two operators could view the various scales and visually control the filling. A system of markers with signal lights set on the rim of the dial scales marked the desired weight of each material for the various classes of concrete, and the operator was directed to fill the batchers until each scale pointer coincided with the illuminated marker.

In the early automatic plants there was considerable tendency to overdesign them to make them fully automatic. Well-designed automatic plants have advantages wherever operating and maintenance costs can be reduced, and in special cases where, for example, the aggregate is fed to four or more mixers in succession. This places a high demand on the rate of batching aggregates which extends beyond the point of normal human operation. The automatic system is fully justified wherever high-speed production is an important factor. The usual accessories such as mix selectors, batch meters, solenoid valves, interlocks, and mercury switches must be of high-grade workmanship to assure reliability of operation.

For some of the smaller plants the argument has been offered that an automatic plant reduces the number of operators, but this is frequently not the case where unreliable equipment is used, because in place of a second operator, it is usually necessary to keep an electrician around to prevent shutdowns in the concrete plant and in all of the placing system, due to faulty connections or other electrical trouble.

Automatic equipment is generally satisfactory where it must function to replace limitations of human control. There is great danger on construction jobs of trying to make things too automatic when it is really necessary to have a certain number of men around at different stations in any case, and it would normally be better to keep the men busy with manual operations, especially when this leads to simplification and greater reliability

of operation. Automatic equipment should preferably be of a type which will allow the main operations to continue under emergency methods in the event of failure of the automatic system.

Proper control of the discharge of the various batchers has an important bearing in getting effective mixing action and quick delivery to the mixers. The discharge should be no faster than the mixers can take and should be so regulated that the dry materials are combined in the desired proportions, and a preblended material hits the mixer blades. This varies with different sizes and types of mixers but was so effective at Grand Coulee that only 2 min. mixing time was required instead of the usual 2½ to 3 min. The cycle time was 25 sec. to weigh, 2 min. to mix, and 12 sec. to empty the batchers. On the second contract the mixing time was reduced to 1 min. 50 sec.

The flow of materials from batchers to mixers should not be arrested in the collecting hopper, and it is important to allow the air to escape as the materials enter the mixer. Water should be added during the period of charging and should strike the face of rolling materials in the mixer to secure a quick saturation. A slight delay in charging the cobbles is effective in bringing down any hang-over materials.

Concrete Mixers.—Concrete mixers are obtainable in standard sizes of ⅓-, ½-, ¾-, 1-, 2-, 3-, and 4-cu. yd. capacities. There are two standard types of stationary concrete mixers, the tilting and nontilting types. The tilting type is found more commonly on large construction jobs because it has the advantage that aggregates of 6 to 8 in. and larger can be used without difficulty, whereas with the nontilting type such aggregates are liable to foul the discharge chute and damage it. For aggregates of small sizes, especially from 3 in. and lower, nontilting mixers are usually satisfactory and have the advantage of simpler charging and discharging spouts. In an effort to simplify the charging spouts on tilting mixers, with a consequent reduction in the height of the mixing-plant structure, there has recently been developed a front-charging and discharging mixer (Fig. 118) which was used successfully on the Tygart and Grand Coulee dams. The proper design of the blades proved to be a major problem in perfecting this new type.

In the tilting mixer the mixing action is largely one of rolling the material from end to center and on itself whereas in a non-tilting mixer the material is not only rolled but also lifted in the buckets and then dropped. In some cases this is a serious consideration where there is a tendency for the large aggregate to spall and develop an excess amount of fines which tend to dry up the mix. The design of the blading requires careful consideration to reduce the tendency of concrete accumulating

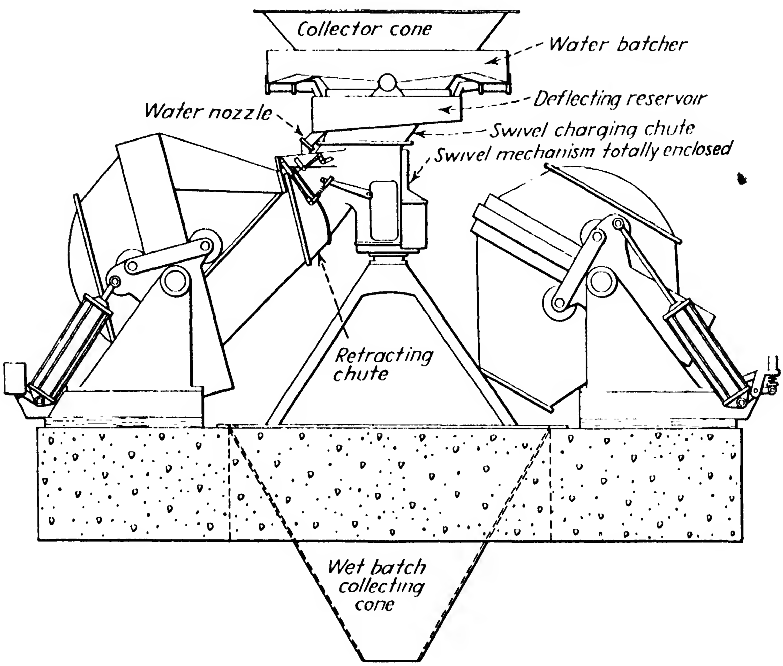


FIG. 118.—Modern arrangement of front charging and discharging tilting mixer in a large mixing plant.

between the blades and packing up, particularly when making relatively dry concrete. The tilting mixer is more satisfactory for dry concrete.

A rapid discharge is of great importance in mixers because the mixer time cycle, as a rule, defines the time cycle and output for the rest of the operations. The mixing time for large mixers is now generally accepted as follows: 2-yd. capacity and less, 2 min.; 3-yd. capacity, 2 to 2½ min.; 4-yd. capacity, 2½ to 3 min. In some cases it has been found feasible to shorten the

mixing time somewhat, especially where the charging and mixing action is effective in rapidly producing a uniform batch as determined by careful analysis of samples taken from various points within the mixer. Table 41 gives the horsepower and weights for standard mixers. For special jobs the use of truck-mixer units or dual-drum mixers deserves consideration.

TABLE 41.—STANDARD LARGE-SIZE CONCRETE MIXERS

Size	Nontilting			Tilting	
	Capacity, cubic yards	Horsepower of motor	Weight, pounds	Horsepower of motor	Weight, pounds
56-S	2	40	22,000	30	25,000
84-S	3	60	27,000	40	30,000
112-S	4	75	46,000	50	45,000

Tilting mixers are, as a rule, equipped with removable liners which can be replaced. It has been found that if these liners are surfaced with a special hard welding rod their life can be very materially extended. It is usually worth while to apply such a welded coating to the interior of mixers, as the maintenance costs are thereafter substantially reduced. Such welding should be applied with proper consideration of the mixing action so that at points of extreme wear the hard surface may be made especially thick. At Norris Dam the hard welded surface was applied on the interior of the drum and on the blades. Each mixer produced about 300,000 cu. yd. of concrete with only slight retouching of the lining. The blades were built up about every 40,000 cu. yd.

By installing a wattmeter in the circuit of the mixer motor it has been found feasible to get some approximation of the consistency of the concrete in the mixer. A very dry mix takes more power than a soft mix, and the information thus gained helps to control the quality of the concrete before it leaves the mixer. A more accurate device has recently been developed for front-charging mixers which measures the axial reaction of the revolving drum, and this can be calibrated to give a measure of the consistency of the contents.

Operating Instructions.—After the mixing plant has been designed it is highly desirable to develop a detailed operating

chart which describes the functions of all parts of the plant and indicates what each operator is expected to do. Such advance planning of operations will reveal any defects in the system and will also prevent misunderstandings and the need for a long period of training operators by trial and error.

Transfer of Concrete.—The selection of suitable transfer equipment depends primarily on the adopted type of concrete-placing plant and on the loading facilities at the mixer end.

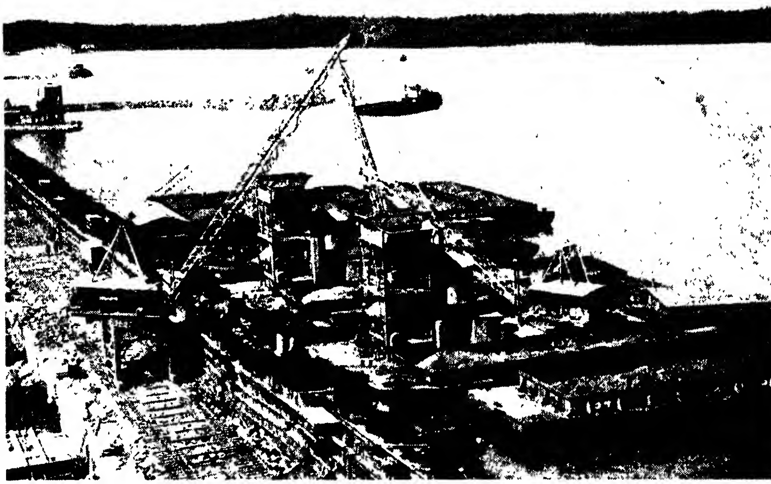


FIG. 119.—Floating mixing plants at Wheeler Dam; concrete-placing crane at left.

This interrelation deserves considerable study, as is further described in Chap. XXIII. It is also important to preserve the quality of the concrete by avoiding segregation and preventing delays during the time between discharging the concrete from the mixers and placing it in the forms. This is particularly important in hot weather where "flash setting" may occur rather suddenly, and such a premature and partial consolidation renders the concrete unfit for final placement.

Where the concrete is discharged by the mixers directly into buckets it may be transferred either by cranes, in case of short reach (Fig. 119), or on trains (Fig. 120), or, where the distances are relatively short, on trucks. Handling of concrete in buckets is considered one of the most satisfactory methods because

segregation is reduced to a minimum and it is possible to handle a drier mix, which means that the concrete may be designed with a substantial economy in cement. Most of the standard buckets on the market have conical bottoms and segmental discharge gates, which are satisfactory for concrete with a slump of 3 in. but frequently fail to release dry concrete with a slump of 1 in.,

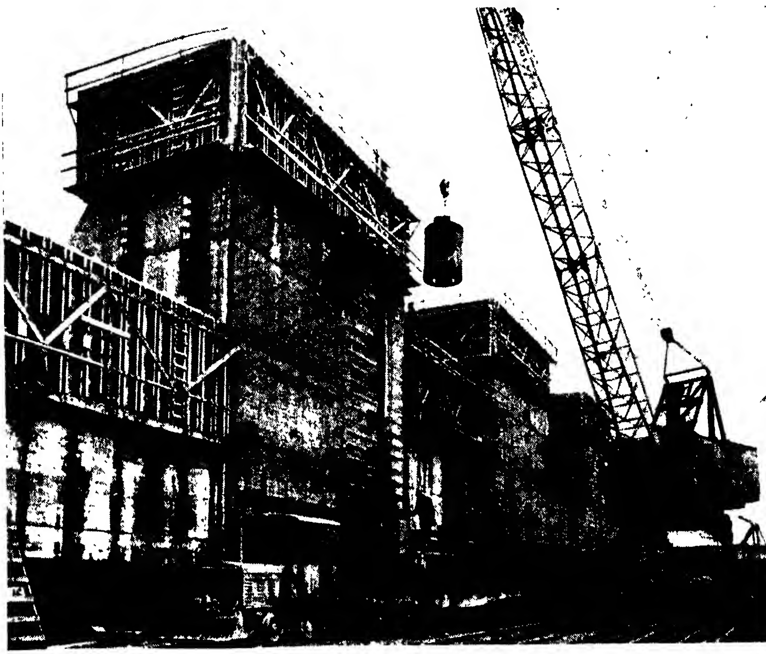


FIG. 120.—Buckets of concrete delivered by transfer train from mixing plant to gantry whirler crane for placement.

as is sometimes used in massive structures. Special buckets with straight sides and full bottom discharge which can handle such dry concrete, have been designed. The use of compressed-air rams to operate the discharge gates, as introduced at Norris Dam by Ross White, has helped to simplify the handling of dry concrete in large buckets.

At Norris Dam the concrete was placed by cableways. Because of the difficulty and loss of time in releasing empties and picking up loaded buckets, a bucket was left attached to each cableway hook and the concrete was transferred from the mixing plant in special cars with tilting skips which were designed to

raise and dump the concrete into the buckets. For this purpose the transfer cars were connected to locomotives of the gasoline-electric type so that the electric generators could be used not only for propelling the equipment but also for operating the tilting skips. At Marshall Ford Dam flat cars carrying 8-yd.

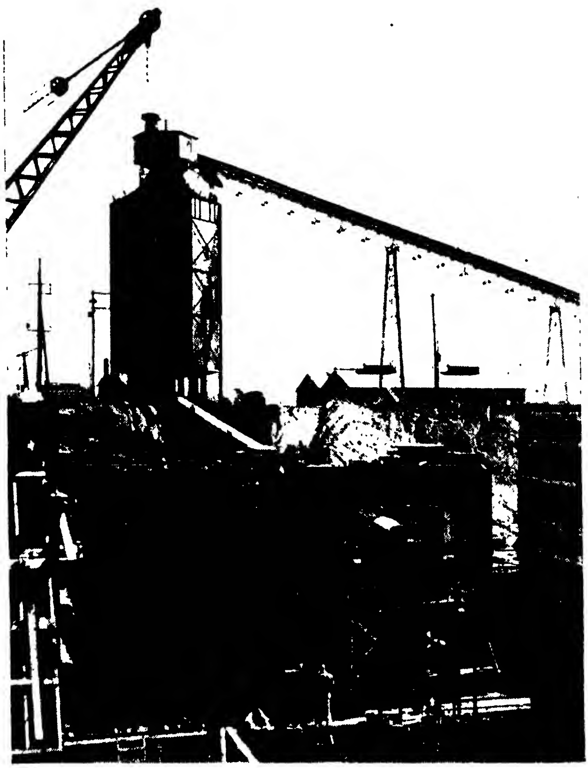


Fig. 121.—Belt conveyor delivers concrete from mixing plant to bucket loading hopper.

concrete buckets were shuttled between the mixing plant and cableway, and in this case shifting the cableway hook from bucket to bucket was done efficiently. To do this the pickup point must be in one general location and near the end of the span where the change in sag is minimized.

Another satisfactory transfer means is the belt conveyor (Fig. 121), even for dry concrete, provided it is fed to the conveyor in a continuous ribbon to prevent segregation, and provided, also, that the discharge end is designed to prevent

segregation due to centrifugal force. The usual tendency is for the larger aggregates to fly off and the fine aggregates and cement mortar to adhere; suitable wipers of the Robins motor-driven type, to prevent return travel of the cement paste, together with baffles and very narrow, deep receiving hoppers designed to remix any segregated materials, are essential features of belt-conveyor layouts. The maximum up-grade angle is 12 deg. for grout and wet concrete, and the best speed range is 150 to 200 ft. per min. Deep troughing idlers are essential, spaced at not more than 2½ ft. centers. When conveying downgrade, a change in grade must be avoided or the concrete will tend to pile up and spill. On downgrades the concrete tends to slide ahead on the belt and accumulate at the lower end to the point of spilling over the sides. To prevent this the belt speed should be increased to around 300 ft. per min.

A high-pressure water spray on the return belt will prevent dry concrete from accumulating on the belt (see also Chap. XXIV). With a long belt-conveyor layout there are usually several yards of concrete on the belt, and it is more difficult to handle four or five different kinds of mixes, some of which are sometimes required to come in sequence, and in such cases the handling in buckets deserves further study. Furthermore, in the case of holdups or shutdowns, there is a considerable quantity of concrete retained on the belt which may lose its quality if held too long. The belt is a transporting device and is not satisfactory for distribution in the forms. At the loading end a vibrating pan type of feeder has been found most satisfactory.

Figure 122 shows various suggestions, tabulated by Lewis E. Tuthill, for handling concrete on belts or in chutes without segregation.

For secondary distribution, buggies, chutes, and tremies are standard items of placing equipment.

Concrete Pump.—A recent development in transfer equipment, which at the same time is also a placing unit, is the concrete pump, which has had a rather satisfactory acceptance in a specific field. It is quite important that its field of usefulness be properly recognized because there are some places where the nature of the aggregate or the nature of job is such as to make it unsuitable, and nothing is gained in trying to use the pump in such places.

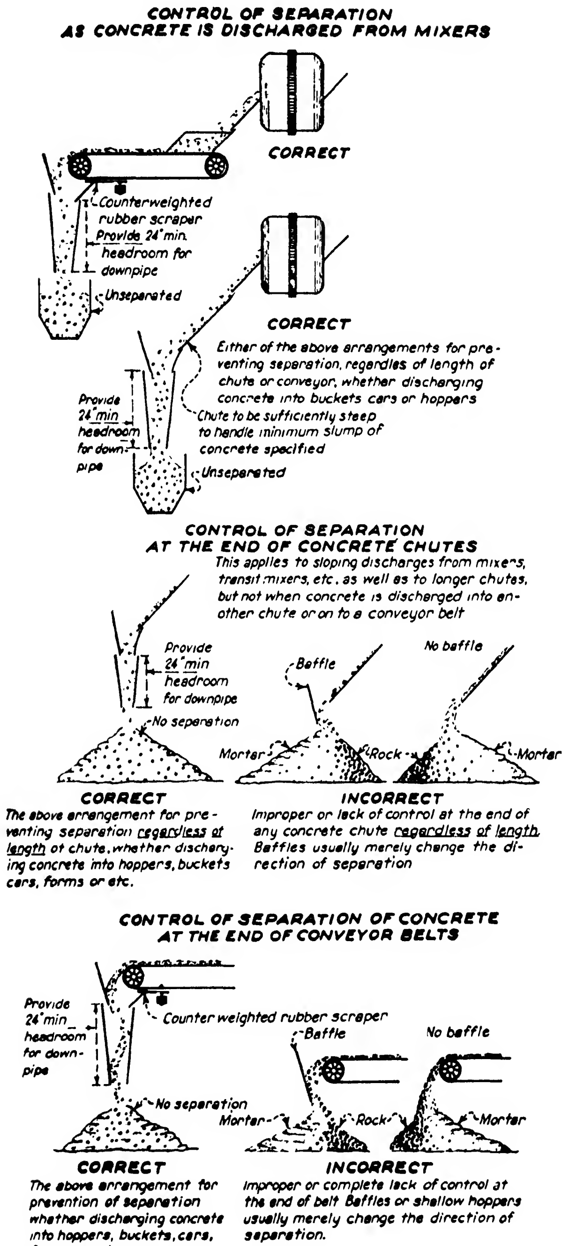


FIG. 122.—Suggestions for handling concrete on conveyors and in chutes.

The "Pumpcrete" unit, as it is known in this country, is designed to move plastic concrete through a pipe line by a direct-acting pump. The unit consists of an overhead hopper with an agitator blade, a set of valves through which the pump cylinders are filled, similar valves on the discharge side of the cylinder which open when the cylinder is full, and a direct-acting plunger, which pushes the concrete forward into the pipe line. The valves are operated by eccentric rods driven by the plunger shaft. It takes about a 50- to 60-hp. motor to operate such a unit, which is capable of moving concrete a distance of 1,000 ft. at a rate of 50 to 60 cu. yd. per hr. A vertical pumping distance of 185 ft. has been attained. The pump is designed so that all wearing parts can be readily replaced. With certain kinds of aggregates or harsh sand, this may be a considerable item of expense.

Harsh concrete is not readily pumped. The best slump is about 3 in., which is a concrete of very satisfactory quality. The largest size aggregate which can be pumped by this equipment is about 3 in. This does not mean a large amount passing a 3-in. screen size, where there may be elongations of greater dimensions, but preferably occasional stones of this maximum size mixed into a uniform composition. For this size, 8-in. pipe is used and the largest size of pump available.

The pipe used with this equipment is of special design in 10-ft. lengths and either 6, 7, or 8 in. in diameter with special toggle connections for quick assembling or dismantling. There are also special bends, 90, 45, and 22½ deg., together with adapter sections. A line is usually good for about 50,000 cu. yd. As a general rule, it is more difficult to pump vertically than horizontally, and the equivalent of 1 ft. vertical is about 8 ft. horizontal (see Table 42).

TABLE 42.—PERFORMANCE OF CONCRETE PUMP

Pipe size, inches	Horizontal pumping distance, feet	Vertical pumping distance, feet	Maximum size of aggregate, inches
8	1,000	100	3
7	800	100	2½
6	600	100	1½

After the equipment has been in service and pumping is to be discontinued, the pipe is cleaned out by means of a special

element known as a "go-devil," which is shoved through the pipe behind the last concrete by water under pressure, and the water at the same time washes out the pipe.

This type of equipment is particularly useful as a supplemental unit for a main placing plant in order to reach inaccessible

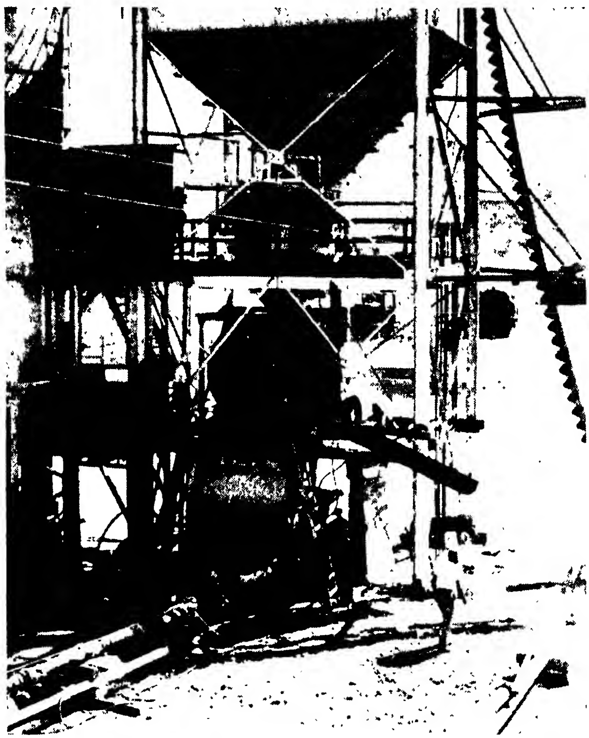


FIG. 123.—Concrete pump being charged by overhead mixer.

places, or on certain large jobs where the work is spread over great areas and is of a rather complicated nature. On the Imperial Dam in Arizona (Fig. 123), the entire project, with 120,000 cu. yd. of concrete, was placed by means of pumping equipment. Concrete pumps have also been used with considerable success on tunnel and subway lining jobs.

CHAPTER XXIII

CONCRETE PLACING AND FORMS

It is better to overplant than to underplant. This principle deserves the most careful consideration when it comes to laying out the placing equipment for a large dam project. The placing system is usually the main feature of a plant layout, and if it is designed adequately to meet the "natural rate of construction" or the schedule as set up by other requirements, the other related plant units can readily be designed to accommodate the demands of the placing plant.

The placing plant is usually the most expensive element, and there is, therefore, a natural tendency to restrict the expenditures for it or to economize wherever possible. This may lead to wide divergence of opinion as to the best method of doing a job. Every constructor who has laid out a plant for a large project will recall that, except in a few cases, he has been obliged later to add an extra derrick or one or two cranes or some other auxiliary equipment to meet unforeseen demands. It is difficult to visualize all the operations for several years ahead on a large dam-building project. If the plant is designed to meet most of these operations without allowing for a so-called factor of ignorance, certain times are bound to occur when additional capacity would be very useful either to make up for lost time or to take advantage of unforeseen breaks which, if they could be utilized, mean an extra profit.

Some of the principles with respect to general plant layout have been discussed in Chap. V. Furthermore, the mixing, transferring, and placing of concrete are so closely interrelated that it is necessary to analyze these various operations as one in making a layout. The problem of designing the proper capacity in a mixing plant was discussed in Chap. XXIII, and a table of output experiences from various large projects was presented there. The significant point, which is here repeated, is that the maximum possible output of a plant for one day has very little

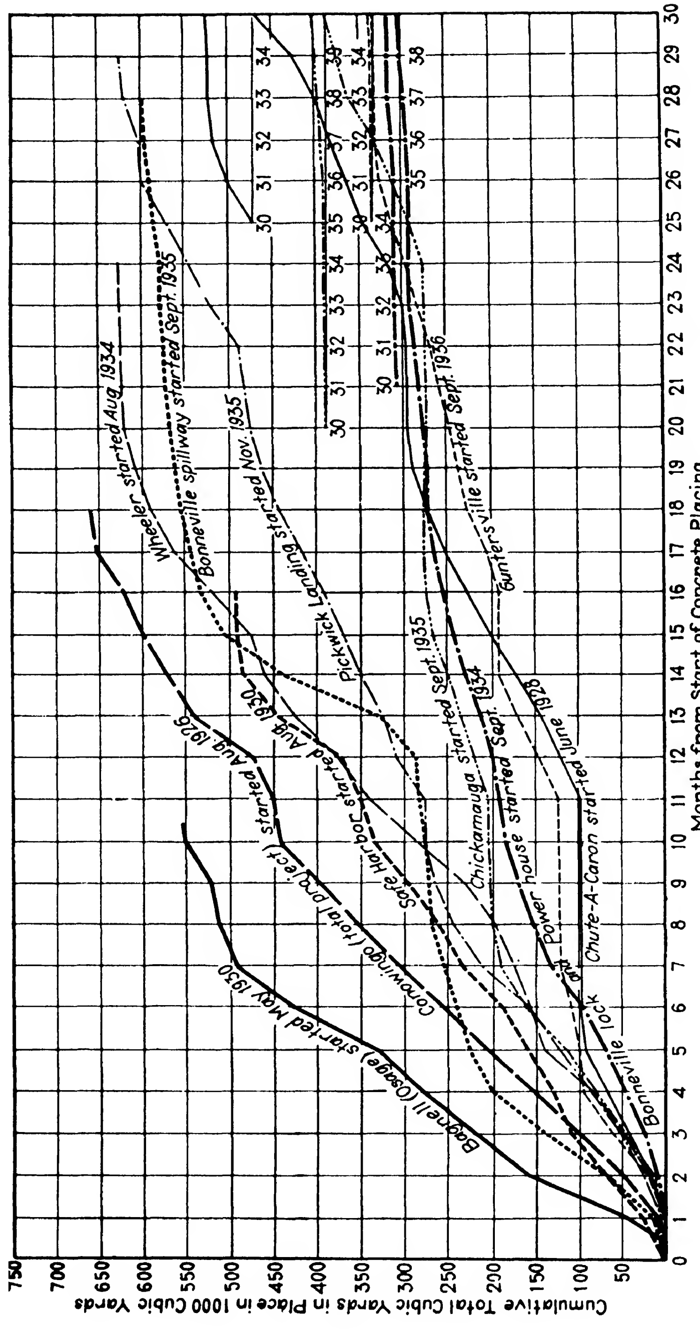


FIG. 124.—Progress curves of concrete placement in large wide-river dams.

importance, and, although a record-breaking performance is usually widely acclaimed, it should be kept in mind that it is the average *continuous performance* over a long period of time which defines the efficiency of a plant and organization and which also limits the profit in a job.

Figures 124 and 125 represent a collection of curves showing the rate of placing concrete on most of the large projects built

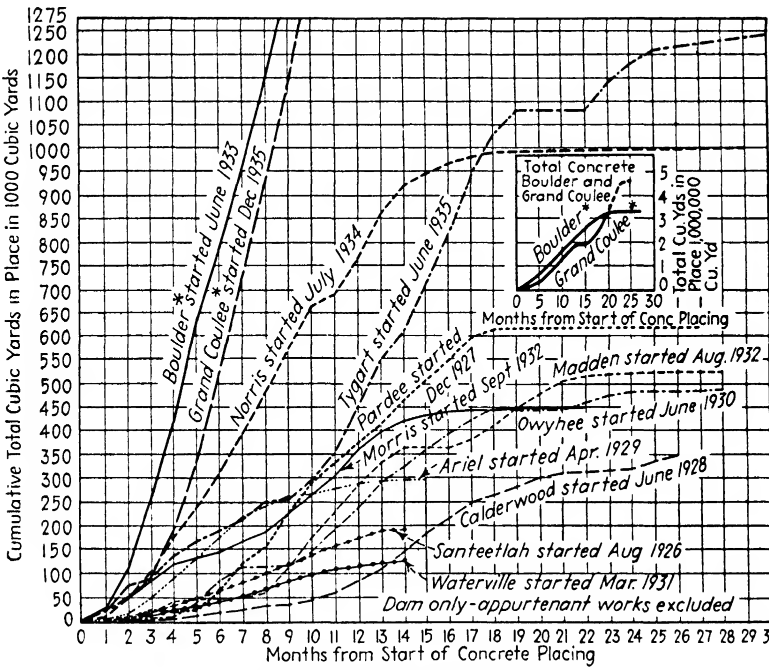


FIG. 125.—Curves showing cumulative volumes of concrete placed in large canyon-type dams.

during the last 10 years. The average slope of each line represents the rate of placing concrete over long periods, and although in almost every case there are some rather steep slopes in the curves, which indicate the actual ability of the plant, it is the flatter over-all slopes which define over-all performance. These flatter slopes mean that other circumstances, such as handling of the river, building cofferdams, winter weather, limitations in the permissible rate of raising concrete, or other factors, had a controlling effect. In some cases the plant itself was a limiting factor, owing to the necessity of making revisions in layout

TABLE 43.—CONCRETE-MIXING AND PLACING SYSTEMS ON LARGE DAM PROJECTS
(Canyon type)

Project and year completed	Quantity concrete, cu. yd.	Aggregates			Mixing equipment		Transfer equipment		Placing equipment	
		Type	Source	Transported	No.	Type	No.	Type	No.	Type
Hoover (Nevada Arizona, 1936)	4,400,000	Natural sand and gravel	Pit deposit (7 miles to screens and 4.7 miles more to mixers)	To screens: four trains, 90-ton steam locomotive and 7- 10- and 30-yd. cars. To mixers: by railroad in 50-ton hopper cars	2	Complete plants, each with four 4-cu. yd. mixers; single material automatic weighing batchers: 4 cement, 2 water, 1 for each aggregate size	5 5 1	18-ton electric locomotives; 30-ton Diesel locomotives; flat cars carrying 2 buckets, space for 4; 4,000-ft. haul; stiffleg derrick, 136-ft. boom	5	25-ton cableways: 2 at 2,575-ft. span; 2 at 1,405-ft. span; 1 at 1,365-ft. span
Grand Coulee (Base section) Washington, 1937)	4,070,000	Natural sand and gravel	Glacial deposit (bank pit) 1½ miles from site	Belt conveyors 48-in., 5,975 ft. to storage; 36-in. on 4,400-ft. suspension bridge to west mixer; 36-in. to east mixer	2 7 8	Complete plants, each with four 4-cu. yd. tilting mixers front-end charging and discharging; automatic weighing batchers; aggregate bins, aggregate capacity 1,150 cu. yd.; cement capacity 1,350 bbl.	10 10	10-ton Diesel locomotives; 36-ft. railroad flat cars, carrying 4 buckets, space for 5; inclined track, carrying 4-cu. yd. skip to railroad cars on low level trestle	2 7 60	3,000-ft. steel railroad trestles; hammerhead cranes 4-cu. yd. buckets
Tygart (Pennsylvania, 1937)	1,166,000	Natural sand and gravel	Dredged from Ohio River	Railroad in 70-ton bottom-dump cars, 85 miles to site	4 6	3-cu. yd. tilting mixers; automatic single material weighing batchers, 4 aggregate, 2 cement	3	36-in. belt conveyor; 10-ton narrow-gage locomotives, each hauling special cars carrying two d-cu. yd. bottom-dump concrete buckets	4 15	Gantry-mounted whirler cranes; 3-cu. yd. bottom-dump buckets
Norris (Tennessee, 1936)	999,300	Crushed sand and rock	Quarry near site	36-in. and 30-in. belt conveyors to screening and storage and mixing plant	3 1	3-cu. yd. tilting mixers; set of 8 single material weighing batchers (air controlled); aggregate bins, capacity, 1,200 tons	3 3	8-ton gas-electric locomotives; 6-cu. yd. special 2-skip hopper dump cars	2 2	18-ton traveling cableways; span, 1870 ft.; traverse, 475 ft.; 6-cu. yd. special air-dump concrete buckets
Pardee (California, 1929)	617,000	Natural river-run sand and gravel	Gold dredge spoil bank screened and washed at site	Aerial tramway 18,700 ft. with 1-cu. yd. buckets; capacity, 220 tons per hr.	4	2-cu. yd. drum-tilting mixers; volumetric aggregate and cement weighing batchers	1 2	Chute to base of steel tower; 2-cu. yd. tilting skip buckets hoisted to top of placing tower	1 1	Insley tower and chuting system; 10-ton cableway handling forms, etc.; span, 1,280 ft.

Madden (Panama, 1934)	550,000	Natural sand and gravel	River bar pit in Chagres River	Aerial tramway 5,355 ft. with 1-cu. yd. buckets; capacity, 225 tons per hr.	3 6 1	2-cu. yd. tilting mixers; aggregate batchers; cement batcher; aggregate bins, capacity 1,200 tons	2 2	8-ton gasoline locomotives; 8-cu. yd. special 2-skip hopper dump cars	1 1 1	25-ton traveling cableway, span, 1,325 ft.; traverse; 410 ft.; 8-cu. yd. concrete bucket
Owyhee (Oregon, 1932)	550,000	Natural sand and gravel	Pit deposit	By railroad 24 miles to site; three steam locomotives and 66 steel hopper cars; three trains daily	2	4-cu. yd. tilting mixers; cumulative weighing batchers	3 3	8-ton gasoline locomotives; special 2-skip center dump cars, capacity 4-cu. yd. per skip	1	25-ton radial cableway span, 1,306 ft.; tail tower on 475-ft. radial track; 8-cu. yd. concrete buckets
Morris (Pine Canyon; California, 1931)	450,000	Natural sand and gravel	Commercial pit	Railroad 2 miles; aerial tramway 10,200 ft.; 500-ft. lift; capacity, 235 tons per hr.	2 2 2 2	4-cu. yd. tilting mixers batchers: air-operated, manually controlled cumulative weighing aggregate; weighing cement; metered water	2 2 2	48-in., 70-ft., belt conveyors; small locomotives; small flat cars, each carrying one 4-cu. yd. bucket	2 1	10-ton radial cableways with common head tower; tail towers on radial track; spans 958 and 962 ft.; 20-ton stiffleg derrick; concrete chutes; 4-cu. yd. bottom-dump buckets
Calderwood (Tennessee, 1930)	346,000	Crushed sand and rock	Tunnel excavation, foundation excavation, quarry	One 70-ton locomotive and five 20-cu. yd. cars	2 1 1	Mixing plants, one with 2-cu. yd. tilting mixer, and one with 4-cu. yd. tilting mixer; volumetric aggregate batches; metered water batchers; weighing cement batchers		Locomotive hauling 4-cu. yd. or 2-cu. yd. buckets on flat cars; maximum haul, 2,000 ft.	12	20-ton guy derricks with 100- to 125-ft. booms; 2- and 4-cu. yd. concrete buckets
Diablo (Washington, 1930)	316,000	Natural sand and gravel	River-bed deposit	Incline railroad 300-ft. lift. 68 per cent slope, in ballast cars; standard-gauge locomotive; 2,000 ft. to site	4	1-cu. yd. tilting mixers; weighing batchers; mixer storage, 8,000 cu. yd.		Chutes to base of concreting towers	2	Hinged conveyors, suspended from masts delivered concrete through large hoses to forms; conveyor end positions adjustable by mast and tag lines
Ariel (Washington, 1931)	306,000	Natural sand and gravel	River bar at site	Sauerman excavator and belt conveyors	3	2-cu. yd. tilting mixers; weighing batchers	6	7-ton gasoline locomotives hauling 1 to 2 flat cars with 2-cu. yd. bottom-dump buckets	3 4	Whirler derricks handling 2-cu. yd. bottom-dump buckets guy and stiffleg derricks
Santeetlah (North Carolina, 1927)	215,000	Crushed sand and rock	Quarry 4 miles from site	One 70-ton locomotive and thirty 20-cu. yd. cars	2	2-cu. yd. tilting mixers		Locomotives and one car carrying four to six 2-cu. yd. buckets; maximum haul, 2,200 ft.	12	20-ton guy derricks with 90-ft. booms; 2-cu. yd. buckets
Waterville (North Carolina, 1932)	123,000	Crushed sand and rock	Tunnel excavation and quarry	Railroad on narrow gauge up to 12 miles, haul length varied with tunnel length	2	2-cu. yd. mixers; weighing batchers	1 2	Narrow-gauge gasoline locomotive hauling flat car; 2-cu. yd. bottom-dump concrete buckets	2	Whirler cranes on skids on temporary bridge

TABLE 44.—CONCRETE-MIXING AND PLACING SYSTEMS ON LARGE DAM PROJECTS
(Wide-river type)

Project and year completed	Quantity concrete, cu. yd.	Aggregates			Mixing equipment		Transfer equipment		Placing equipment	
		Type	Source	Transported	No.	Type	No.	Type	No.	Type
Conowingo (Pennsylvania, 1928)	663,000	Natural sand and gravel	Commercial production from Chesapeake Bay	Railroad cars; gravel hauled 4 miles to site	2 4 2	Plants and two contracts; 2-cu. yd. tilting mixers; 2-cu. yd. tilting mixers; batchers; sand mundators; gravel, cumulative, weighing; cement weighing	10	8-ton gasoline locomotives; 2-cu. yd. side-dump hopper buckets; standard-gauge 36-ft. flat cars	2 7 4 3 7 7	Steel railroad trestles full length of dam; 40-ft. gauge traveling gantries, carrying 220-ft. wood towers, 100-ft. steel towers; chuting systems; stiff-leg derricks
Wheeler (Alabama, 1936)	627,000	Natural sand and gravel	Dredged from river bottom	Towboats and barges; up to 50 miles to site	4 1 1 1 1 1 1	Floating plants, each with 90- by 40- by 7-ft. steel barge; 75-ft. boom whirler crane; 2-cu. yd. tilting mixer; set weighing batchers (multiple type); 500-bbl. cement silo; set aggregate bins		No intermediate transfer	6 6	Traveling whirler cranes with 95-ft. booms; four on 14-ft. gantries; two on low trucks; 2-cu. yd. bottom-dump buckets
Pickwick Landing (Tennessee, 1938)	610,000	Natural sand and gravel	Dredged from river bottom	Towboats and barges; 5 to to 10 miles to site	3 7 7	2-cu. yd. tilting mixers; weighing batchers; 5 aggregate, 1 cement; 1 water; mixer bins· 6 aggregate, total capacity, 750 cu. yd.; 1 cement, capacity 750 bbl.	1 3 1 1	30-in. belt conveyor flight; 10-ton gas-electric locomotives; 12-ton fixed cableway, span, 1,270 ft.; 5-cu. yd. bottom-dump cableway bucket	2 1 11	6-ton gantry-mounted whirler cranes; 12-ton gantry-mounted whirler crane; 2- and 3-cu. yd. bottom-dump concrete buckets
Bonneville (Oregon, 1938)	597 000	Natural sand and gravel	River-run pit deposits	Railroad gondola cars; 25 to 50 miles to screening plant at site	4 2	4-cu. yd. tilting mixers; sets single material automatic weighing batchers	3	8-ton gasoline locomotives hauling special 2-skip, 8-cu. yd. capacity hopper cars	2	20-ton radical cableways 223-ft. common fixed tail tower; two 90-ft. traveling head towers on 892-ft. track; span 2,022 ft.; 8-cu. yd. bottom-dump buckets.
Bagnell (Missouri, 1931)	551,000	Natural sand and gravel	Dredged from river; some sized aggregate purchased	Barge to screens; by steam locomotives and hopper cars to site	4	2-cu. yd. tilting mixers; weighing batchers; 4,000-cu. yd. live storage	6	8-ton gasoline locomotives hauling one flat car each; four 2-cu. yd. side-dump hoppers on each car	1 3	Steel trestle full length of dam; traveling electric gantries with 10-ton derricks, and concreting towers with chutes and elevators

Chute-à-Caron (Canada, 1931)	524,000	Natural sand; crushed rock	Sand from glacial deposits; rock from foundation excavation	Sand by railroad 1 to 5 miles. Rock by railroad from storage of excavated materials	2 2 1	4-cu. yd. tilting mixers; volumetric aggregate and water batchers; cement weighing batcher	10	40-ton steam locomotives, hauling concrete buckets on flat cars, 4 buckets per car	2 54	Stiffleg gantries; guy derricks; straight-side bottom-dump buckets; 38 of 4-cu. yd. size; 16 of 2-cu. yd. size
Safe Harbor (Pennsylvania, 1931)	513,000	Natural sand; crushed rock	Dredged from Chesapeake Bay; rock quarry 1,000 ft. from site	20 steam locomotives; hauling hopper-bottom cars; sand hauled 50 miles	4 4 4 4	2-cu. yd. mixers; cumulative weighing aggregate batchers; weighing cement; siphon water	7	10-ton gasoline locomotives; standard flat cars, carrying four 2-cu. yd. side-dump hoppers; 1 car per train	1 4	Steel trestle full dam length; 40-ft. gauge traveling gantries with 100-ft. steel towers and stiffleg derricks; concrete chutes; derrick booms; 3 at 85 ft.; 1 at 100 ft.
Chickamauga (Tennessee, 1939)	460,000	Natural sand; crushed rock	Sand from commercial pit; rock from quarry 1 mile from site	Sand by railroad in gondola cars; rock by 30-ton Diesel locomotive hauling four 18-cu. yd. cars	2 1 1	2-cu. yd. tilting mixers; set single material weighing batchers; 6-compartment aggregate bin	1 to 3 3 3	30-in. belt conveyor flights; 8-ton gasoline locomotives; 40-ton flat cars with space for three 2- or 3-cu. yd. concrete buckets	2 5 5	6-ton whirler cranes, gantry-mounted, with 75-ft. booms; 2-cu. yd. bottom-dump buckets; 3-cu. yd. bottom-dump buckets
Guntersville (Alabama, 1939)	310,000	Natural sand and gravel	Dredged from river bottom	Towboats and barges; 5 to 10 miles to site	2 1 1	2-cu. yd. nontilting mixers; set single material; weighing batchers; 6-compartment aggregate bin	1 to 3 5	30-in. belt conveyor flights; 10-cu. yd. trucks, carrying two or three 2-cu. yd. buckets	3 12	6-ton traveling whirler cranes, gantry-mounted; 2-cu. yd. bottom-dump buckets
Bonneville (Lock and power-house, Oregon, 1936)	240,000	Natural sand and gravel	Dredged from river; barge haul 2 miles to screening plant at Portland, Ore.	Sized material by railroad in bottom-dump hopper cars to aggregate plant at site; haul 40 miles	2	3-cu. yd. tilting mixers; single material automatic weighing batchers	3	8-ton gasoline locomotives hauling special 2-skip, 8-cu. yd. capacity hopper cars	2 2	15-ton radial cableways; 145-ft. common fixed head tower; 75-ft. tail towers on 579-ft. track; span, 1,400-ft.; 6-cu. yd. bottom-dump buckets
Rock Island (Washington, 1932)	235,000	Natural sand and gravel	Pit deposit	5-cu. yd. trucks; 2 miles	4	1-cu. yd. tilting mixers; weighing batchers	4	8-ton gasoline locomotives, hauling 1-cu. yd. steel hopper cars 350 ft. to trestle	1 2	1,100-ft. steel trestle; 5-ton gantry cranes with elevator and chuting system

during the course of a job, such as relocating the placing or delivery equipment and similar changes. Tables 43 and 44 give the basic features of plant layout for most of these projects.

After the average rate of placing and the duration of the job have been established in terms of maximum economy, taking account of all related factors, a theoretical capacity must be established to serve as an output figure for which all interrelated plant units are designed. We are then ready to discuss output and capacity in terms of individual cycles. A convenient way

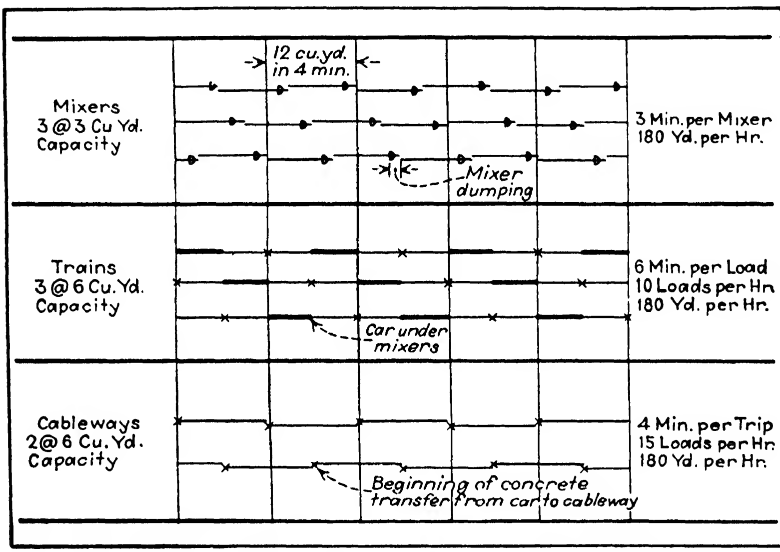


FIG. 126.—Operating diagram of time cycles for concrete mixing, transferring, and placing at Norris Dam.

to analyze plant requirements in terms of such cycles is to set up diagrams similar to the one shown in Fig. 126. This shows the cycle performance for the mixers in the mixing plant, the transfer cars, and the cableways at Norris Dam. By timing each unit for its maximum output and efficiency and properly interrelating these, the job is so locked together that all parts of the plant will function efficiently whenever conditions permit operation of the placing equipment at its maximum output. In some cases it is necessary to consider longer distance of travel for transfer cars and other equipment, and the proper selection of speed, capacity, and number of units may necessitate four or five such diagrams before the most efficient combination becomes apparent.

Placing of Concrete.—The most commonly accepted modern machines for concrete placing are derricks, whirler cranes (Fig. 120)—traveling on track runways or special elevated trestles—cableways (Fig. 127), belt conveyors, special gantry or hammer-head cranes, and Pumpcrete machines. The various types of hoisting equipment are described in greater detail in Chap. XXIV.

Dispatching Systems.—Of considerable importance in obtaining proper functioning of a large integrated plant is an effective dispatching system. This must be thoroughly studied at the

FIG. 127.—Cableways delivering concrete at Norris Dam also provided maximum freedom for handling river.

time the plant is designed so that every requirement with respect to dispatching and expected performance is known in advance. If a competent dispatcher is located at some strategic point where he can observe all operations and in special cases or emergencies can signal or telephone instructions to the right point, he can keep the entire system functioning without confusion and loss of time.

As a rule when a large system breaks down at one point or another, it takes considerable time to get all interrelated parts functioning together again in proper tempo, and for this reason the maintenance of output through effective dispatching is exceedingly important. The dispatching instructions and regulations should be described on charts and issued to all members of the operating organization so their duties are properly under-

stood. Usually numerous special cases develop which cannot be covered by instructions, but if each man knows his job under regular conditions it is easier for him to take care of exceptions.

Preparations for Placing Concrete.—An important element of plant which is frequently considered a mere detail but has considerable bearing on progress, speed, and effective starting of operations at the beginning of a shift is the cleaning equipment for foundations and for completed surfaces of concrete. It is usually necessary to clean off all laitance and impurities before the concrete has set completely, and various types of brushes and high-pressure air and water jets or sand-blasting equipment are important accessories in a placing outfit.

Compaction of Concrete by Vibrators.—The use of vibrators for the compaction of concrete has practically reached the status of standard practice. There is little justification for using wet or "sloppy" concrete when the use of vibrators gives a thorough compaction.

With vibration the quality of the concrete is improved and a substantial economy results because vibration permits the use of a drier mix containing less cement and permits the use of a greater percentage of large aggregate. Under difficult conditions the placement of concrete is made easier (Fig. 128) and compaction more effective, and the work of adding patches on exposed surfaces after removal of forms is largely eliminated.

There are two general types of vibrators: the external type and the internal type. The external type, which was first used for mass concrete, consisted of a platform with a vibrator mounted on top. This has largely been displaced by the more effective internal vibrator. The principal use for external units is now largely on precasting forms or on screeds for concrete-pavement placing, or for placing canal lining.

The internal vibrators have proved most efficient because the impact is entirely absorbed by the concrete; there is no loss of energy above its surface; and the tendency for aggregate segregation is practically eliminated. Where a charge of 6 or 8 cu. yd. of concrete is placed at one time with a reasonable amount of spread, a number of ball-type electrical vibrators or air-driven cylindrical-type vibrators can consolidate such a mass in relatively short time. It is important to have enough vibrators so that the rate of placing of concrete is not retarded.

The rapid strides in the design of vibrators made to date indicate that the future will probably see additional new developments. The present trend is toward higher frequencies and higher amplitudes of vibration. From 5,000 to 7,000 impulses per minute are considered desirable, and where these are not obtained through standard 60-cycle power sources, a frequency

FIG. 128.—Electric vibrators for compacting concrete.

converter is a necessary addition to the vibrating equipment. The bearing design is of utmost importance in vibrators, and above all the equipment must be regularly serviced and overhauled to prevent local failures.

Compressed-air vibrators are free from electrical troubles and are readily adapted where air is available for cleanup and other purposes. However, the air hose connected to the vibrators is more cumbersome than the smaller electric cable.

Forms.—The subject of forms deserves a great deal of study because on the average lock and low dam project forms represent from 30 to 40 per cent of the cost of concrete and on high dams

from 15 to 20 per cent of such cost. One of the first questions is: To what extent can panel forms be used and reused, and to what extent is it necessary to build "in place" forms. This requires advance consideration of the total square feet of coverage, the square feet of uniform surface, form-handling facilities, capacity of the concrete-placing plant and expected output, the height of lift, pressures against forms based on the rate of rise of concrete, and the cost of labor.

Panel forms, as a rule, are economical where they can be used five times or more. Panel forms are still in the development stage, and great economies are still possible in improving their design and use. In the past it has been largely left up to the carpenter foreman to work out a standard panel and then make many hundreds of them, but more recently the advantages of combining his experience with careful design and experimentation have disclosed the value of such precautions. In addition to sound and practical design, the use of good hardware and lumber, thorough supervision, and speedy handling facilities are essential to the successful use of panel forms. Where these points are not fully realized, the extra labor cost of handling special panels may greatly offset their advantages.

As an example of cost distribution in the handling of panel forms, the following is from a typical job:

PANEL-FORM COSTS

	Per Cent
Panel depreciation	23.2
Erection	21.4
Stripping	8.0
Safety scaffolds	4.9
Hardware (embedded)	19.2
Miscellaneous	23.3
Total	100.0

There has been a tendency to use steel panels for large dams, but in almost every case it was concluded that lumber panels would be more satisfactory. This is largely so because of the many special structural or architectural features that must be incorporated on the face of the dam, and in addition it is necessary to support reinforcing steel and a large variety of piping and inserts which require the cutting or penetration of panels for pipe, electric conduits, and similar elements. Furthermore, the

weight of steel panels places a limitation on their size and usually requires a larger number to be handled than is necessary when lighter timber panels are used. As a rule, steel reusable forms are best adapted to continuously recurring types of structure such as tunnel linings, culverts or walls of a great length, or for arch centering when there are a large number of duplicate arches. As a general thing, the steel traveling forms have not been found satisfactory for navigation lock walls because of the many nonuniform features that occur in such structures.

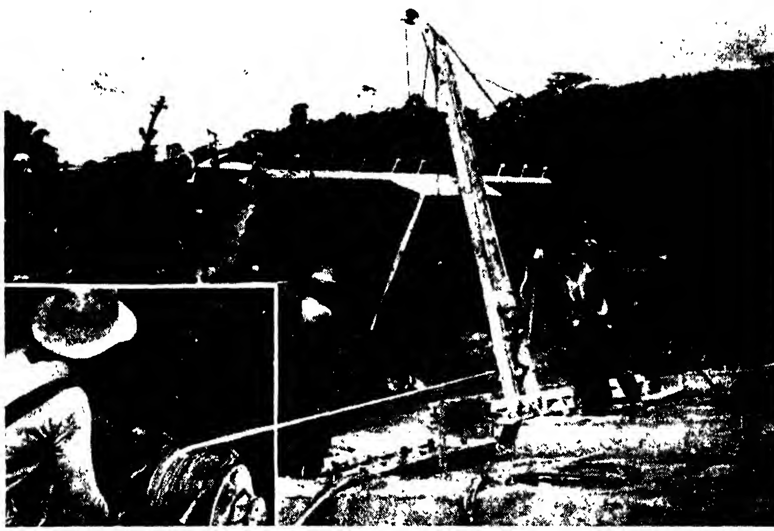
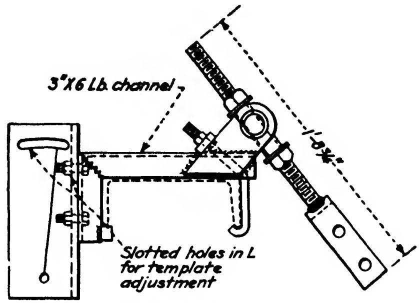


FIG. 129.—Panel forms being handled by simple hoisting rig and crew of four men.

On the Madden Dam, 400 panels were used in the double-row step-up method. These were made up of No. 1 Douglas fir for 5-ft. lifts 14 ft. long, each weighing about 1,200 lb., and consisted of eleven 2- by 6-in. vertical studs, 2- by 6-in. sills, 1- by 6-in. sheathing, 6- by 6-in. waler, and were faced with 16-gauge metal. All junctures were bound with metal bands, and the panels were very rigid, could stand considerable abuse, and still were relatively light to permit easy handling by a crew of 4 men, as shown in Fig. 129. This was one of the most economical form-handling systems ever devised.

At Norris Dam the double row of panels was also used, employing 470 panels, each for a 5-ft. lift averaging 14 ft. long, and were made considerably heavier, about 2,050 lb. For handling the



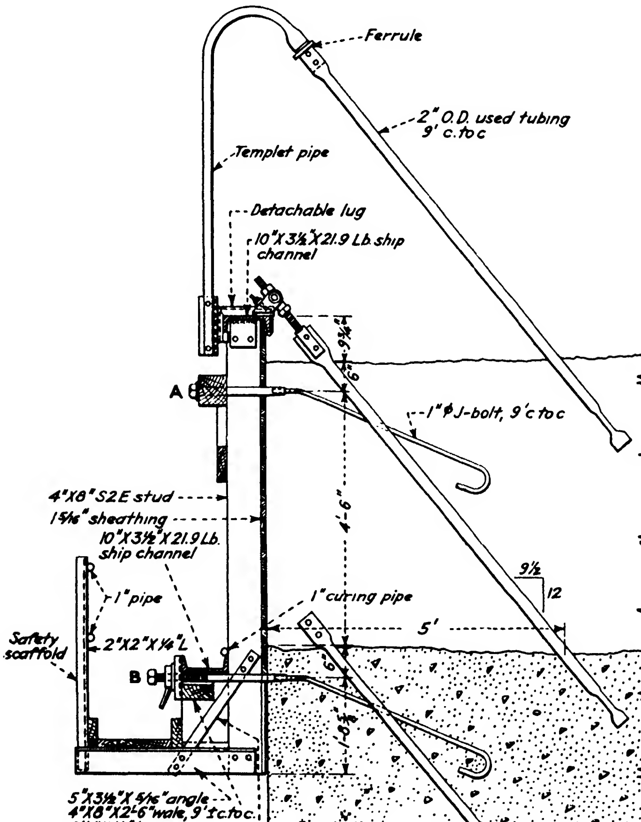


FIG. 130.—Details of panel forms used on Hiwassee Dam.

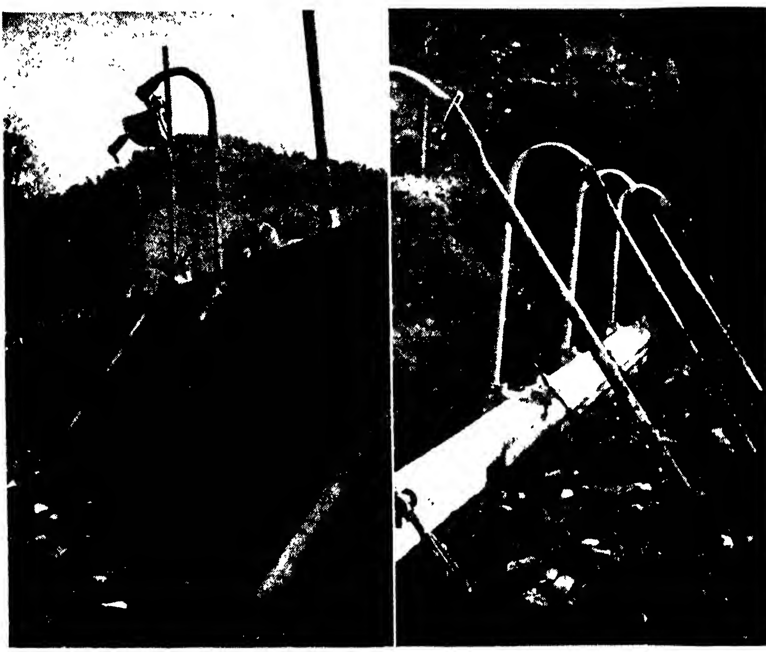
panels a special small crane was employed which could travel on top of the completed concrete surface. This was moved from block to block by the overhead cableway.

On the Chickamauga lock and dam the single-row sliding-panel system was used; 220 panels were made up, each 12 ft. high by 14 to 18 ft. in length. Most of the concrete was placed in 10-ft. lifts. An innovation in the panel-form design called for a steel channel top sill (previously introduced at Pickwick Landing Dam) to displace the usual timber waler. On large panels this channel sill has a number of advantages in simplifying the structural arrangement of the panel members and in serving as the point of connection for the tie rods which are embedded in the concrete. (See illustration of panels in Fig. 120.) The Chickamauga panels were made up of 1½-in. sheathing, double 3- by 10-in. studs spaced on 2-ft. centers, and were held in place by 2-in-pipe combination struts and tie rods placed at 4-ft. centers.

Among the recent advances in panel design and use, in addition to the steel channel sill mentioned above, is the greater use of the single-row sliding-panel system over the double-row step-up system, which requires almost twice as many panels. The use of the latter system is hardly ever justified now, since most specifications require 3 days between lifts. This gives enough time for the concrete to set and hold the anchor bolts for the forms, instead of depending upon the lift below to supply the necessary structural support for them. Another important and desirable feature is the use of coarse threads on all screw fittings, which helps to speed up erection and stripping. Although most heavy mass concrete is placed in 5-ft. lifts, 10-ft. lifts are more economical in smaller structures, and such higher lifts should be employed wherever the quality of the concrete is not adversely affected thereby.

An interesting idea in panel forms and form hardware was introduced by J. E. Walters on Hiwassee Dam. The panel forms on the upstream and downstream faces were made the full length of the concrete blocks, and these panels were lifted repeatedly toward the top of the dam. Some of the panels were reused forty times. An essential feature of all panels on their exposed faces was a convenient walkway with railing so that the workmen could readily manipulate the anchor bolts or other fastenings without endangering themselves (see Fig. 130).

The most interesting feature of these panels is shown in Fig. 131. Anchorage is obtained by means of 1½-in. secondhand pipe with flattened ends. As a lift of concrete is nearing completion these pipes are shoved into the wet concrete and their upper ends are temporarily connected to templet arms, which hold these pipes in proper relationship during setting of the concrete; when the panel form is subsequently lifted for the next pour the fastenings on the form come into position opposite the ends of the



(a) (b)

FIG. 131.—(a) Combination strut and tie rods for panel form; (b), temporary support for rods

embedded pipe, and a quick attachment with a convenient adjustment is all that is necessary to line up the panels. The lower edge of the panel is anchored to the previously placed concrete with horizontal anchor bolts, which are removed subsequently when the panel is ready to be raised. The pipe acts as both a strut and tie rod to keep the panel in true alignment, and this is very effective since a high degree of rigidity is essential when dumping 8 yd. of concrete alongside the form. Figure 132 shows the type of portable A frame which is set alongside the

panel form for raising the panel; it is operated by working a small jacking device attached to a roller chain.

Some effort has been made to develop various cantilever-type forms which dispense with tie rods, but it is difficult to hold such forms in alignment when placing concrete with 4- or 8-yd. buckets. Furthermore the first cost of such cantilever forms is substantially higher than the simpler tie-rod-type forms and their use is, there-

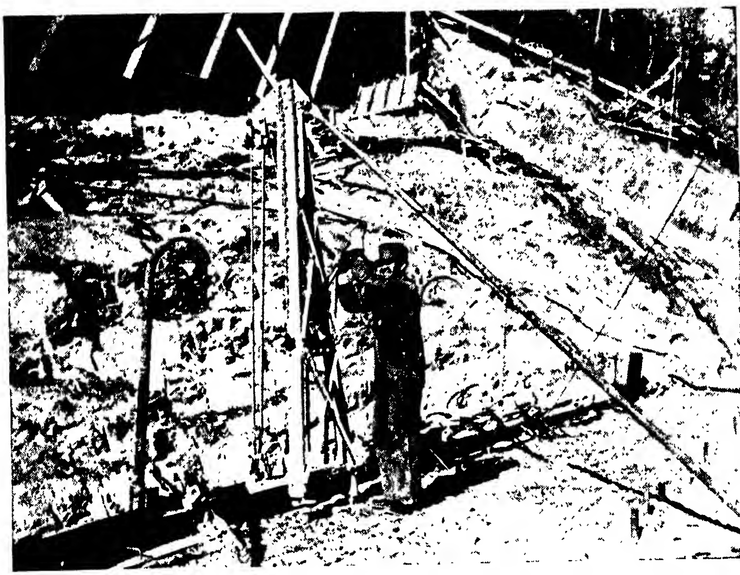


FIG. 132.—Portable A frame for manually raising form panels.

fore, justified only where there is a saving in cost of embedded parts and of labor in handling and setting.

Handling of Forms.—Of equal importance to the design of panel forms is the management of their handling. Materials should all be available at the beginning of a shift. The panels should be equipped with means for retaining all reusable fittings to prevent their dropping off and causing a loss of time while replacements are obtained.

It has been well established on recent projects that it is more economical to provide a small portable A frame for hoisting up the panel forms rather than use the regular concrete-placing or other large hoisting equipment. Raising the panel is usually a short-period operation which is only a small part of the cycle. The

form must be held in place while various bolts and other connections are threaded to the previously placed concrete, and the form costs mount rapidly if expensive hoisting equipment is used for such holding service. On routine form-handling operations the carpenter crew should be able to operate independently of special hoisting service.

Also, where the stripping is done by cranes, the panels are usually stored on the ground until a carpenter crew is available, and this means that the panels tend to become warped or damaged in such handling. The panels should be well oiled so that they will strip without difficulty. Safety scaffolds are important because they mean greater freedom of action for the men and greater speed.

Design of Forms.—Douglas fir is one of the most common types of lumber for form panels. On the TVA jobs southern yellow pine was used, designed with working stresses of 1,200 lb. per sq. in. in flexure and 125 lb. per sq. in. in shear. It is necessary, as a rule, to hold deflections down to $\frac{1}{8}$ in. or less.

The sheathing should invariably be not more than 6 in. in width; 4 in. is better in order to maintain a true surface on the panels and to simplify repairs. Special surfacing of panels with sheet metal or plywood usually causes water to run down along the smooth face of the forms before the concrete has set, which leaches out the cement and develops sand streaks; this defaces the surface of the concrete. To overcome this and still obtain a uniform surface of concrete, a special absorptive type of form lining was required for Shasta Dam. Each panel of lining was used only once and served to absorb excess water in the concrete, thereby also developing a greater density of the surface concrete.

There has recently been a trend toward designing panels unnecessarily heavy. Handbook data regarding the pressure of concrete against forms usually gives excessive pressures. In recent tests made by H. G. Roby it was found that the pressures depend on a number of variables, such as the rate of placement, the temperature of concrete, the cement content, and the water content. In soft concrete placed rapidly up to 4 or 5 ft., the pressure against forms may correspond directly to the liquid pressure at the unit weight of concrete, but for greater heights the pressures do not increase in such proportions. In the dry mixes it is not feasible to develop full liquid pressures, and the

effect of mechanical vibration is not transmitted over a large area of a panel to introduce excessive pressure.

Concrete-spraying Machines.—A special method of concrete placing, particularly for surfacing or repairing buildings or walls, is known as the Gunite process, and a more recent modification by Westberg is known as the Shotcrete process. In the Gunite process a mixture of cement and sand is prepared in a special mixing unit known as a "cement gun" which is subjected to air

FIG. 133.—Nozzle for spraying concrete coating on walls.

pressure, and this forces the mixture through a hose and special nozzle against the surface to be coated. In both processes the moisture is supplied to the sand-cement mixture at the nozzle through a separate water hose. There is a certain percentage of rebound sand, which can be collected and used over again.

The Shotcrete equipment has a charging hopper in which a dry mixture of sand and cement is proportioned, and a rotary feeding device transfers the mixture at a uniform rate to a pressure chamber where it is assisted toward the outlet by a revolving screw; here compressed air is admitted to carry the material through 1½- or 2-in. rubber hose to the nozzle (Fig. 133).

Conveying distance of 500 ft., together with a rise of 125 ft., has been employed. Shotcrete equipment is available in capacities of 3, 7, and 12 cu. yd. per hr., for which air compressors with ratings of 160, 300, and 500 cu. ft. per min., respectively, are required. Operating pressures at the gun are between 28 and 45 lb., with the pressure at the compressor at about 60 lb. per sq. in.

CHAPTER XXIV

HOISTING AND CONVEYING EQUIPMENT

Hoisting equipment is gradually and definitely improving. Rope speeds have been increased, the drums hold more cable, steel cut teeth have largely displaced cast-iron gearing, the gears are guarded more effectively, and asbestos-fabric-type brake linings have largely displaced wooden blocks.

Derricks were used extensively at one time in both the stiffleg and guy type, but their slower swing and fixed setting have led to a more general use of whirler cranes.

Whirler Cranes.—The whirler crane is essentially a traveling derrick, combining the long boom of the derrick with a self-contained base, so that the entire unit can travel on a track. In contrast with the stiffleg derrick and guy derrick, a whirler has a faster swing and can cover considerably more area because of its traveling features. This machine consists essentially of a gantry or base frame mounted on wheels and supporting a circular track and swinging gear, a live roller circle, and the main rotating structure. The rotating structure has a framework into which are framed the boom at the front and the counterweight at the rear. All necessary hoisting and control equipment is mounted on the rotating platform. The roller circle and track gauge are of considerable width, ordinarily 14 to 16 ft. gauge so that the center of gravity is inside the roller path under all load conditions. Figure 120 shows a typical whirler crane. Figure 134 is a similar machine mounted on a pontoon-type hull for river work. The capacities for standard whirler cranes with various boom lengths and at various radii are given in Table 45. For special cases the reach of a whirler can be extended by using lightweight aluminum booms.

The travel of the gantry is ordinarily obtained through separate motors mounted on two diagonally opposite corners of the gantry sills or trucks and connected to the wheel axles through

TABLE 45.—MODELS AND OPERATING CHARACTERISTICS OF STANDARD WHIRLER CRANES

MODEL No.	C-10	C-14	C-17	C-20	C-24
Diameter of rail circle, feet	10	14	17	20	24
Size bucket for sand and gravel, cubic yards	1¼	1½ and 2	3	4	5
Size bucket for coal, cubic yards	2½	3 and 4	6	8	10
Tons per hour (sand, gravel or coal)	125	150 to 200	250 to 300	400 to 500	550 to 650
Length of standard boom, feet	65	75	80	80	80
Hoist motor, electric, horsepower	75	75 or 100	150 or 200	200 or 300	300 or 375
Hoist engine, steam, inches	9½ by 10	10 by 12	12 by 14	12 by 16	12 by 16
Swing motor, electric, horsepower	25	30 or 40	50	75 or 100	100 or 125
Swing engine steam, inches	6 by 6	6½ by 8	8 by 10	9½ by 10	10 by 12
Line pull, pounds	10,000	12,000	20,000 or 24,000	24,000 or 30,000	28,000 or 35,000
Sheave diameters, in.	18 and 20	24	27 and 30	27 and 30	27 and 33
Rotating speed, r.p.m	2	2	2.25	2.25	2.25
Capacity, 35-ft. radius, tons	11.5	15.0	30.0		
Capacity, 40-ft. radius, tons	9.7	13.5	26.0	40.0	
Capacity, 45-ft. radius, tons	8.2	12.0	22.5	35.0	50.0
Capacity, 50-ft. radius, tons	7.2	11.0	19.0	30.0	45.0
Capacity, 55-ft. radius, tons	6.2	10.0	15.0	25.0	40.0
Capacity, 60-ft. radius, tons	5.5	9.0	14.0	20.0	35.0
Capacity, 65-ft. radius, tons	5.0	8.0	12.5	17.5	30.0
Capacity, 70-ft. radius, tons	. .	7.5	11.0	15.0	25.0
Capacity, 80-ft. radius, tons	. .	. . .	10.0	12.5	20.0
Capacity, 90-ft. radius (125-ft. boom), tons	. .		8.0	10.5	15.0
Capacity, 100-ft. radius (125-ft. boom), tons			6.0	9.0	12.0
Capacity, 115-ft. radius, (125-ft. boom), tons				7.5	10.0

AVAILABLE LIFT, IN FEET, ABOVE BOOM FOOT FOR VARIOUS WORKING RADII

Length of boom, feet	Radius from center pin, feet							
	20	30	40	50	60	70	80	90
65	65	63	58	52	42	25		
75	73	70	66	60	52	40	15	
85	83	80	76	72	65	55	42	15

spur-gear reductions. This arrangement is very simple and permits the whirler to travel along curved tracks.

In general the type of hoisting unit installed in whirlers is used on other types of derricks. Such hoists are driven either by steam from a boiler built into the unit or by electric motor. Considerable improvements have been made in recent years by developing simple and positive operator's control levers of the direct mechanical type or of hydraulic or air-pressure type.

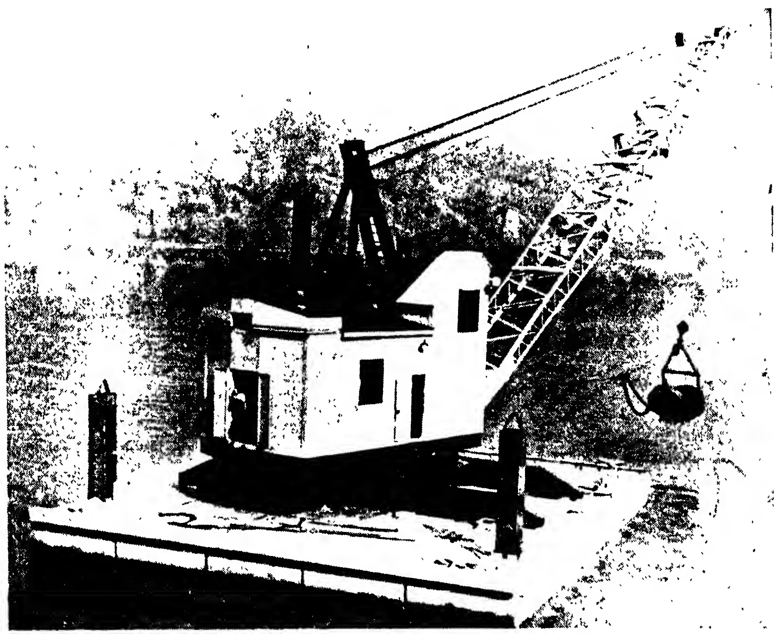


FIG. 134.—Whirler crane mounted on pontoon type of hull for river dredging. Hull is sectionalized to fit railroad cars.

The whirler is a very compact and efficient contractor's tool which can be readily adapted to a large variety of work where hoisting is required.

Other Types of Cranes and Hoists.—Crawler-type excavating machinery equipped with crane booms for crawler-crane service is useful in a wide range of work. Table 46 shows the reach and capacity of a 2-yd. excavator equipped with various length booms for service as a crawler crane. Where a contractor expects to use a crawler crane for concrete placement or other continuous-cycle service the speed of booming and of the various

other motions should be carefully analyzed because several types of cranes have relatively slow booming and single motions.

TABLE 46.—LIFTING CAPACITIES,* IN POUNDS, WITH CRANE BOOM FOR 2-YD. CRAWLER EXCAVATOR

Radius, ft.	40-ft. boom	45-ft. boom	50-ft. boom	55-ft. boom	60-ft. boom	65-ft. boom	70-ft. boom	75-ft. boom	80-ft. boom
12	81,300†	81,100†	81,000†						
13	74,900	74,700	74,600	74,500†					
14	69,400	69,200	69,100	69,000	68,800†				
15	64,700	64,500	64,400	64,300	64,100	63,900†			
16	60,400	60,300	60,200	60,100	60,000	59,800	59,700†		
17	55,600	55,500	55,400	55,300	55,200	55,000	54,900	54,600†	54,400†
20	44,300	44,200	44,100	44,000	43,900	43,700	43,600	43,300	43,100
25	32,400	32,300	32,200	32,100	32,000	31,800	31,700	31,400	31,200
30	26,000	25,900	25,800	25,700	25,600	25,400	25,300	25,000	24,800
35	21,400	21,300	21,200	21,100	21,000	20,800	20,700	20,400	20,200
40	18,000	17,900	17,800	17,700	17,600	17,400	17,300	17,000	16,800
45	....	15,500	15,400	15,300	15,200	15,000	14,900	14,600	14,400
50	....	....	13,600	13,500	13,400	13,200	13,100	12,800	12,600
55	....	....	....	11,900	11,800	11,600	11,500	11,200	11,000
60	....	....	....	....	10,600	10,400	10,300	10,000	9,800
65	....	....	....	....	....	9,300	9,200	8,900	8,700
70	....	....	....	....	....	....	8,300	8,000	7,800
75	....	....	....	....	....	....	....	7,200	7,000
80	....	....	....	....	....	....	....	....	6,300

* All capacities are based on 75 per cent of the overturning load with unit standing on firm, level ground.

† This is rating at minimum working radius obtainable with this length of boom.

Double-cylinder steam hoists have become generally standardized, as listed in this table:

TABLE 47.—DOUBLE-CYLINDER STEAM HOISTS

Size of steam engine, inches	Horsepower usually rated	Maximum line pull, pounds	Line speed, feet per minute
7 by 10	23	7,000	175
8¼ by 10	30	8,500	175
9 by 10	44	10,000	175
10 by 12	58	13,000	175
12 by 12	65	16,000	175
12 by 16	75	20,000	220

Although these are conventional horsepower ratings, the power plant furnished is generally capable of as much as 75 per cent more than the rated horsepower. By changing gear ratios and

reducing the line pull the drum speeds may be increased proportionately to 200 or up to 500 ft. per min. Steam hoisting equipment is particularly suitable for floating plant because it makes such equipment independent of a power source. Furthermore, steam equipment can stand a great amount of overload and is especially suited to conditions involving frequent acceleration, since the acceleration is simply proportional to the applied pressure. Because of this characteristic and torque requirements, the corresponding electric hoists require motor equipment rated about double the horsepower rating of steam hoists.

Electric hoists of similar capacities are also available, and in the heavy-duty field they run up to 80-, 100-, and 125-hp. capacities and from there on into extra-large sizes up to 400 and 500 hp. Standard hoists providing two line speeds are also available through a large range of sizes. The speed, power, and safety of hoisting equipment have been constantly improved through experience gained on construction work.

Cableways.—The cableway is a particularly efficient tool. It can be spanned over the working area and therefore frees the working area of the usual supports for other types of hoisting equipment. The use of small and relatively inexpensive cableways is very common in Europe but for some strange reason is uncommon in this country, although the indications are that there is a considerable field for such equipment.

A standard cableway consists of two towers of the fixed or traveling type which support a track cable spanning the working area. One end of the track cable is usually connected to a multiple-part line to provide a convenient means for adjusting the sag. A carriage travels on the track cable and from this the necessary hoisting line and sheave blocks are suspended, which in turn carry the load.

Movement of the carriage is obtained by means of an endless line which connects to the carriage on one side, runs to the head tower and down to an endless-cable drum around which the line is wrapped five or six times then up to the top of the head tower again and across the full span to the tail tower through a set of sheaves and terminates on the other side of the carriage. The section of endless line running from the carriage direct to the hoist is called the "in-haul" line because pulling on this line causes motion inward toward the head tower, and the other

section of endless line running from the other side of the carriage to the tail tower and then to the hoist is called the "out-haul" line because pull on this line by the hoist causes the carriage to travel outward from the head tower. The hoist line runs from the carriage through the head tower and down to a second drum. When the endless-cable drum is held stationary and the hoist drum moves, the load travels up or down but does not travel sideways. When both drums operate together the load travels sideways but not up or down. In standard equipment the load moves either horizontally or vertically, and not on a diagonal.

It is usually necessary to support the hoisting and in-haul lines on traveling slack-cable carriers which are normally stationed at about 200-ft. intervals along the track cable. They are picked up by a horn on the carriage as it travels in to the head tower, and are dropped off the carriage at the designated positions as it travels out. This spacing is accomplished through a separate button line which is equipped with enlargements or buttons securely clamped at the desired intervals. The buttons are progressively larger going away from the head tower. The button line is threaded through eyes or loops on the slack cable carriers, and these loops are of varying sizes corresponding to the sizes of the buttons. As the carriage with the carriers travels out, the first small button prevents the smallest eye on the last carrier from continuing its travel and it hangs up at this point. As the carriage continues to travel away from the head tower this operation is repeated at each button. Each carrier has a set of small rollers which support the free span of hoist and in-haul line, and this arrangement of carriers prevents the hoist line from sagging down when the load is released from the hook.

In recent years the use of cableways has rapidly increased on large projects, especially after the development of special cables up to 3 in. in diameter of the smooth-surfaced locked-coil type. Such progress was also aided by the adoption of improved designs of cableway towers of the traveling type in place of timber towers which had serious limitations as to structural loading as well as in the arrangement of wheels. Steel towers are almost considered standard now for large projects.

The 25-ton cableway used on Owyhee Dam was the forerunner of the modern heavy-duty cableway, the first of which was used at Madden Dam, where structural steel towers 100 ft. high running on fully equalized wheels, were spaced 1,300 ft. apart and

carried a 3-in. track cable and heavy-duty hoisting equipment capable of handling loads up to 25 tons. Since then similar units of greater span have been employed at Hoover, Norris,[1] Hiwassee, Marshall Ford, Bonneville, and Parker dams.

Figure 135 shows a typical heavy-duty cableway tower. The horizontal thrust wheels at the rear of the tower are mounted on a bracket which supports the counterweight; their use permits full equalizing of the front and rear trucks to carry only vertical

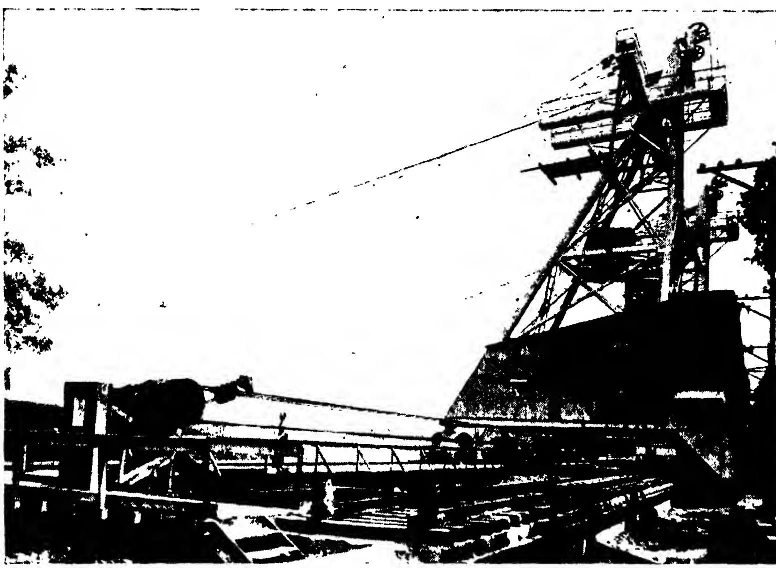


FIG. 135.—Head tower of 20-ton capacity cableway.

reactions. This arrangement of wheels has a special advantage as compared with other types of towers, especially where the tower runways are constructed on earth fill. The fill must be made excessively wide at the front if the horizontal thrust is carried at that point, whereas the special thrust wheels carry this component at the rear and utilize the entire body of the fill for absorbing it, thereby reducing the required size of fill. This arrangement proved especially useful at Norris Dam where a vertical cavern was discovered under the front runway tracks after the cableway had been placed in operation. In the process of excavating the foundation for the dam, a cavern was found at a

[1] "Norris Dam Cableways" by R. T. Colburn and L. A. Schmidt, Jr., A.S.C.E. *Proceedings*, December, 1939.

low elevation, and this connected to a vertical outlet. The clay plug in this cavern slid out one day and caused a serious displacement of the front track, however the rear thrust wheels prevented the tower from falling over and going down into the valley.

On the heavy-duty cableways the towers represent an important investment. They are ordinarily equipped with eight wheels on each corner and this results in a wheel loading of about 60,000 lb. per wheel. The runway costs are correspondingly great. On rock or ground without steel trestle a runway costs about $80.00 per lineal foot plus the price of any high fill below the runway. Where steel trestles are employed the cost, depending on the height, runs from $200.00 to $300.00 per lineal foot of runway. The runway here is considered as including all parallel tracks.

TABLE 48.—HEAVY-DUTY CABLEWAY INSTALLATIONS

Dam projects	Number of cableways	Capacity, tons	Span, feet	Track cable diameter, inches	Hoist power, horsepower	Head tower		Tail tower	
						Height, feet	Type, traveling or fixed	Height, feet	Type, traveling or fixed
Owyhee	1	25	1,306	3	400	65	T	45	F
Madden	1	25	1,325	3	400	100	T	100	T
Hoover	2	25	2,575	3	500	90	T	90	T
	2	25	1,405	3	500	75	T	42	T
	1	25	1,365	3	500	98	F	16	T
Morris (Pine Canyon)	2	15	960	2¼	300	100	F	35	T
Norris	2	18	1,925	3	500	75	T	110	T
Bonneville lock and powerhouse	2	15	1,390	3	400	145	F	75	T
Bonneville spillway	2	20	2,020	3	500	90	T	223	F
Parker	2	25	1,500	3	500	75	T	42	F
Conchas	2	15	1,650	2¼	250	145	T	175	F
Hiwassee	1	18	1,575	3	500	75	T	110	T
Marshall Ford	1	25	2,100	3	500	75	T	177	F
Shasta	6	25	800 to 2,600	3	500	460	F	75 to 125	T

The chief advantage of cableways for dam construction is their universal adaptability to all kinds of service in addition to concrete handling, such as the delivery, directly from a point of unloading to the desired spot, of reinforcing steel, pipe, penstocks,

gate machinery, and the large number of miscellaneous items that are used in the construction of a dam. This avoids the need for various types of access trackways and special hoisting equipment or other rigging arrangements. Furthermore, the resulting complete freedom of handling the diversion of rivers to suit the best and natural conditions of the site permits a greater investment to be absorbed in the cableway installation. Cableways are generally designed to cover the entire construction area and, where feasible, are arranged with the towers at both ends traveling in a parallel direction. In some cases one tower, where it is of unusual height, is fixed, and the tower at the other end is designed to travel on an arc to develop the necessary coverage. Table 48 gives representative data for modern large cableway installations.

In the construction of a dam a single cableway with a capacity of 8 cu. yd. of concrete per trip has performed some very interesting results. For example at Madden Dam, where there were some limitations as to rate of pouring and the dam was not of sufficient size to utilize every minute of operating time, the amount of concrete poured in a single month was 60,000 cu. yd. At Marshall Ford Dam, which was larger and had more available spaces into which to place concrete, 88,000 cu. yd. was placed during the best month, working three 8-hr. shifts. Ordinarily on a 2,000-ft. span an 8-yd. cableway will place a load every 4 min. including all loading and unloading time.

The standard modern cableway as used at Norris, Hoover, and Shasta dams has a carriage travel speed of 1,200 ft. per min., hoisting speed of 300 ft. per min. and lowering speed of 400 ft. per min. At Norris Dam the weight of the head tower, 75 ft. high, was 126 tons, and this tower carried 100 tons of machinery and 390 tons of counterweight. The tail tower, 110 ft. high and weighing 130 tons, carried 50 tons of machinery and 545 tons of counterweight. This cableway was ordinarily rated as a 20-ton cableway and handled 6 yd. of concrete per trip. The hoist line was 7/8-in. flattened-strand plow-steel cable with a working stress of 10,000 lb. The endless line was 1-in. flattened-strand plow-steel cable with a working stress of 14,000 lb. The button line was a 3/4-in. flattened-strand plow-steel cable with a working stress of 6,000 lb. The track cable was 3 in. in diameter locked-coil cable operating with a loaded sag of 5 1/2 per cent. Table 49

gives general data regarding this type of track cable, and Fig. 136 is a chart of calculated tension in 3-in. track cable for various spans.

TABLE 49.—DATA ON CABLEWAY TRACK CABLE
(Special grade locked coil)

Diameter, in.	Weight, lb. per ft.	Breaking strength, tons	Maximum available lengths, ft.	Cost per ft.
2	10	215	4,600	$3.00
2¼	12.5	280	4,600	3.80
2½	15.2	345	3,000	4.75
2¾	18.3	420	3,000	5.90
3	22.2	500	3,000	6.85
3¼	26.0	675	3,000	7.60
3½	30.4	785	2,600	9.20

Careful experiments conducted on the Norris Dam cableway disclosed that the track cable is subjected to surgings, dynamic stress waves, and impact phenomena which result in working stresses being about 30 per cent greater than those computed by standard cable formula. Ordinarily a track cable is estimated to have a useful life for carrying 1,000,000 tons, but recent experiences have demonstrated that 2,000,000 tons and more can be readily handled if proper care is given to the cable. The ends of the cable should be mounted in roller-bearing sockets so that the cable can be turned a quarter turn at periodic intervals, thus distributing the wear uniformly to all sides.

Ordinarily induction-type a.c. motors are employed on cableways, but the Ward Leonard variable-voltage drive has important advantages. An actual comparison for one cycle shows that it takes about 0.204 kw.-hr. per ton of load handled on a cableway when using Ward Leonard control as compared with 0.305 kw.-hr. per ton using standard a.c. drive with automatic acceleration and regenerative braking. Actual experience in the field considering other losses indicate that it takes about 0.5 kw.-hr. per ton for standard a.c. drive. The economies due to Ward Leonard control come from its better characteristics in handling the great amount of acceleration and retardation in this class of service. In acceleration, relatively little extra power is consumed with Ward Leonard control, whereas with a.c. control the excess

power is dissipated in external resistors until the motor is up to speed. In deceleration with Ward Leonard control, power is pumped back into the line, whereas, with a.c. control, power is taken from the line and consumed just as in other parts of the cycle.

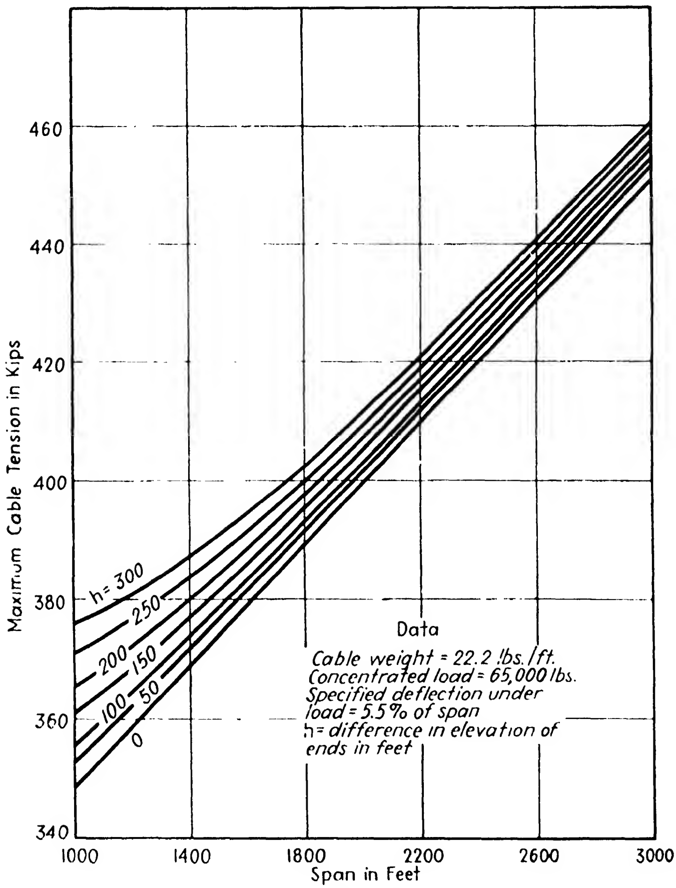


FIG. 136.—Curves of computed maximum tension in track cables for cableway with rated capacity of 25 tons.

Wire Rope.—There are 80 different constructions of wire rope. About 25 of them are in general use. Figure 137 shows representative cross sections for the more commonly used types.

The twist in a wire rope is developed in two standard methods. One is called "regular lay," in which the wires are wound in

opposite directions to the twist of the strands themselves with the result that all wires on their exposed surfaces are parallel to each other. The other is called "lang lay," in which the individ-

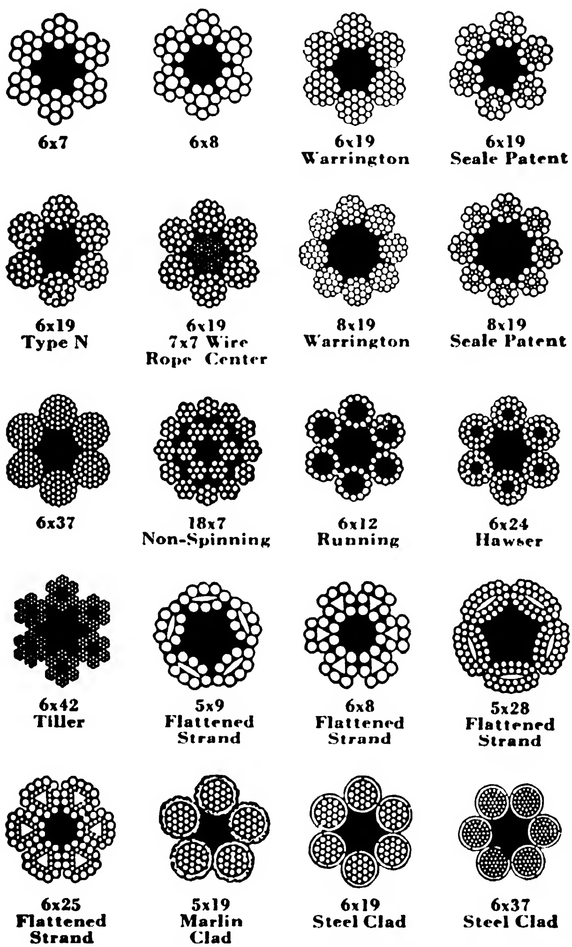


FIG. 137.- Typical cross sections of standard wire rope.

ual wires as well as the strands are wound in the same direction. In both types the individual wires are either deformed during the winding process and tend to spring back when released, or they are preformed in which case the strands and individual wires are at rest in the rope. The lang lay is more flexible than

the regular lay and more resistant to abrasion because three times the length of an individual wire is exposed as wearing surface as compared with regular lay. It is not so commonly used as regular lay because it must be kept taut in service, for it is easily damaged by untwisting or crossing or overwinding on drums. Lang-lay wire is especially good on hard traction pulls or for use as track cables. The introduction of preformed lang lay will no doubt expand its useful possibilities.

The wire ropes are available in a number of different types, such as patented flattened strand and round strand, in which there are six or eight strands with 7, 19, or 37 wires in each strand. This is the more conventional type of wire rope and may have further subdivisions due to various sizes of wire in the individual strands. Then there is the nonrotating type of rope composed of 18 strands of 7 wires each with 12 outer strands laid in one direction and 6 inner strands laid in the other direction. This develops a stable rope which is free from twisting tendencies and makes it particularly suitable for deep shaft or mine hoisting. Other types are the steel clad in which each strand is wound spirally with a flat steel wire, and the lock-coil cable which has almost a smooth surface and is used for track cable on tramways and cableways.

With respect to centers of cable there are hemp centers, wire-rope centers, and metallic core. The wire-rope and metallic-core centers resist crushing and are best for drag cables, track cables, and tension cables for moving heavy loads. This type of cable in the lang-lay twist is particularly good in these services. The metal centers result in a stiffer cable requiring bigger sheaves but add about 7½ per cent to the strength.

It is important to keep wire rope properly lubricated because the flexibility of the wire is obtained by the wires moving with respect to each other, and this means there is considerable friction which can be handled satisfactorily only by lubrication to assure long life.

Wire rope is made in five different grades of steel for the ordinary classes of work. The "improved plow steel" has a strength of the hard-drawn wire in the rope of 230,000 lb. per sq. in. The standard "plow steel" has a strength of 210,000 lb. per sq. in. The "special steel" has a strength of 190,000 lb. per sq. in. The "cast steel" has a strength of 170,000 lb. per sq. in. The iron

TABLE 50.—BREAKING STRENGTH OF VARIOUS TYPES OF WIRE ROPE
(In tons of 2,000 lb.)

Diameter, inches	Approximate weight per foot	Hoisting rope, hemp center							Haulage rope, hemp center			Nonrotating improved plow steel
		Improved plow steel			Plow steel		Cast steel		Improved plow steel	Plow steel	Cast steel	
		Flattened strand 6 by 25	6 by 19	Extra flexible 6 by 37	6 by 19	Extra flexible 6 by 37	6 by 19	Extra flexible 6 by 37	6 by 7	6 by 7	6 by 7	18 by 7
3/8	0.23	6.9	6.3	6.1	5.5	5.3	4.5	4.4	5.9	5.15	4.3	5.8
1/2	0.40	11.8	10.8	10.6	9.4	9.2	7.7	7.7	10.3	9	7.5	10.0
9/16	0.51	14.8	13.5	13.2	11.7	11.5	9.6	9.5	13	11.3	9.4	12.5
5/8	0.63	18.2	16.6	16.1	14.4	14	11.8	11.6	16	13.8	11.5	15.3
3/4	0.90	26.0	23.7	22.8	20.6	19.8	16.8	16.4	22.8	19.8	16.5	21.9
7/8	1.23	35.4	32.2	30.5	28	26.5	22.8	22	30.8	26.8	22.4	29.8
1	1.60	46	42	39.5	36.5	34.4	29.5	28.6	40	34.8	29	38.8
1 1/8	2.03	58	53	49.9	46	43.5	37	36	50	43.6	36.4	49
1 1/4	2.50	71.5	65	61.5	56.5	53.5	46	44.3	61	53	44.5	60
1 3/8	3.03	86	78.5	74.3	68	64.6	55	53.5	73.5	63.5	53	72.5
1 1/2	3.60	101	92.5	88.2	80.5	76.7	65	63.5	86.5	75	62.5	85.5
1 5/8	4.23	118	108	103.3	94	89.8	76	74.3				
1 3/4	4.90	136	124	119.5	108	104	88	86				
1 7/8	5.63		142	137	123	119	100	98				
2	6.40	177	161	155	140	135	114	111				
2 1/4	8.10	222	202	194	176	168	144	139				
2 1/2	10	270	246	237	214	206	176	170				
2 3/4	12.10	323	294	285	256	248	212	204				
3	13.95	See catalogs		337		293						
3 1/4	16.37	for other		392		341						
3 1/2	19.0	types		451		392						
List price of 1-in. rope per foot		$0.60	$0.50	$0.59	$0.43	$0.525	$0.31	$0.37	$0.48	$0.41	$0.29	$0.50

NOTE: For normal working loads use factor of safety of 5. For wire rope centers add 7.5 per cent for strength and 15 per cent to list price.

rope such as used for guy wires and ships' rigging has a strength of 85,000 lb. per sq. in.

Table 50 gives the standard tensile strength for the more conventional classes of rope. Working loads are usually figured with a factor of safety of 5 of the breaking strength. The proper selection of factor of safety varies with the type of load; acceleration; deceleration; rope speed; rope attachment; number, size, and arrangement of drums and sheaves; corrosion and abrasion conditions; duration of use; and the importance of depending on safety to life and property.

To insure that ropes are operating at their proper tension a convenient type of tension indicator is available which clamps around the cable and records the tension in the rope. It is available in sizes of ¼- to 2⅜-in. rope and reads loads up to 250,000 lb. of tension.

The proper selection of sheaves in combination with various types of ropes is ordinarily not given adequate consideration, although this is important to insure long life for the cable. A good sheave should be very hard, of carbon or manganese or other alloy steel, in order to avoid corrugations or cutting of grooves. This will actually reduce wear on the rope because a soft sheave tends to develop corrugations conforming to the rope, and a new rope will not track in the same corrugations.

The conventional practice for different classes of wire rope is tabulated below, giving the proper sheave size for good practice and also for minimum conditions. The sheave sizes are represented in terms of number of rope diameters for different sizes of rope:

TABLE 51.—SHEAVE DIAMETERS IN TERMS OF ROPE SIZES

Type of rope	Rope diameters for good practice	Rope diameters (minimum)
6 by 37 round strand	27	18
8 by 19 round strand	31	21
5 by 28 flattened strand	36	24
6 by 19 round strand 6 by 25 flattened strand	45	30
5 by 9 flattened strand	58	36
6 by 7 round strand 6 by 8 flattened strand	72	42

Belt Conveyors.—There are very few construction operations where belt conveyors in some form are not used. The transfer over short distances of sand, gravel, or concrete is a very simple operation when using belt conveyors and requires a degree of skill considerably less than that involved with other methods. Where longer distances are involved the problem is purely one of economics. If the volume to be handled is very great and the period of time within reasonable limits, the high first cost of a belt conveyor is offset by its greatly simplified operation. This has deen demonstrated more recently on many important earth-moving projects as described in Chap. XV. The elements of a conveyor system are: rubber belting, carrying idlers, return idlers, head pulley, tail pulley, belt tightener or take-up, motor drive and driving gears, and necessary supporting structure or trusses. The most important problems in the design of a conveyor system are frequently centered in the proper feeding, transferring, and discharging of the materials to and from the belt.

For a given problem involving the movement of an estimated volume of material per day it is customary to convert this to tons per hour as the first step in designing a conveyor layout. The performance of the belt is usually based upon the assumption that it carries uniform loads. This, however, may lead to an unsatisfactory solution because it is almost impossible to maintain a uniform feed to the belt, and for the various conditions of irregular feeding, underloading, and overloading it is necessary to make a substantial allowance and design the belt with an ample reserve capacity. For example, if it has been established that 250 tons per hour are to be moved, then the physical and mechanical features of the belt-conveyor system should be designed to carry a uniform load of about 350 tons per hour.

The angle of inclination at which bulk materials may be handled by belt conveyors depends upon the nature of the material. Twenty degrees is ordinarily considered the maximum. The angle of inclination is also dependent to a considerable extent upon the speed of the belt and upon the method of feeding material to the conveyor. If the material is fed to the bell in the same direction and at approximately the same speed as the belt travels, slightly steeper inclinations may be employed.

The following tabulation of angles with respect to the horizontal applies to average conditions:

Material	Angle, Deg.
Sand and gravel, unscreened, damp or dry	20
Sand and gravel, unscreened, very wet	15
Pebbles and screened gravel	14 to 15
Dry sand	15 to 16
Moist sand	20 to 22
Crushed stone	18
Mixed gravel, washed	15
Run-of-mine coal	18
Wood chips	27
Concrete, 2″ slump	20

The foregoing angles apply for average belt speeds of 250 ft. per min. The materials can under certain conditions be conveyed at slightly steeper angles.

Some further discussion of belt conveyors is given in Chap. XX for screening plants and Chap. XXII for concrete handling. Some good illustrations are found in Figs. 67, 105, 108, and 116. Of particular interest is the vibrating feeder shown in Fig. 110. This is a very simple device with exceptionally favorable operating and maintenance conditions.

Belting.– In selecting a belt for a given installation, the number of plies, weight of duck, friction pull (adhesion) between plies, tensile strength, and thickness of covers must be considered. Safe working tensions are listed as follows:

Allowable Tension
(Pounds per ply per inch of width)

Weight of Duck, Ounces*	Tension
28	27
32	30
36	34
42	40

* Weight of a piece 36 in. long in the warp by 42 in. wide.

The several brands of belting manufactured by various rubber companies are classified by friction pull or adhesion between plies and tensile strength of covers. A method of determining the adhesion between plies consists of testing a belt sample 1 in. wide and at least 6 in. long by attaching a specified weight to a ply and timing the rate of separation with

a stop watch. The rate of separation is not to exceed 1 in. per min. The tensile strength of the various brands of rubber cover varies between 300 to 4,000 lb. per sq. in. Durability, resistance against abrasion, and life of the belt are proportionate.

Stepped-ply belts are recommended where the belts are subjected to excessive abrasion at the center or on long, narrow, lightly loaded conveyors on which improved belt troughing is desired. A stepped-ply belt is designated by specifying the number of plies at the center of the belt and the number at each side, *viz.*, 5 by 7, 7 by 9, etc. For design purposes, a 5 by 7 stepped-ply belt is equal in strength to a 6-ply belt, a 7 by 9 to an 8-ply belt, etc. The thickness of rubber on the top side of belting is usually ⅛ in., or greater, in the heavy-duty class.

Idlers.—A good installation of idler equipment for belts up to 36 in. wide usually consists of the three-roll, antifriction-bearing troughing idler, and single-roll, antifriction-bearing return idlers. Special idlers with a thick lagging of soft rubber should be used at all points where material drops onto the belt. Side guide idlers are usually unnecessary and should be avoided wherever possible because they damage the belt edges in time.

The distances between troughing idlers shown on the table below are recommended for the use in the design of conveyors for aggregate and mixed concrete.

TABLE 52.—IDLER SPACING, IN FEET

Material	Wt., lb. per cu. ft.	Size of belt, in.										
		14	16	18	20	24	30	36	42	48	54	60
Sand or crushed stone....	90 to 120	4½	4½	4½	4½	4	4	3½	3	3	3	3
Mixed concrete..........	150	...	...	...	...	.	2	2	2	2½	2½	2½

Pulleys.—The head or drive pulley should have a diameter in inches approximately equal to five times the number of plies in the conveyor belt. The drive pulley should have a high crowned face with a $\frac{3}{16}$ or ¼ in. per ft. slope, and lagged with not less than four-ply rubber belting riveted or bolted to the pulley.

The use of pulleys having diameters smaller than recommended makes it necessary to increase the belt tension so that the belt

will hug the pulley, which increases the stresses in the plies of duck. Excessive bending also causes the belt carcass to fail and splices to break due to extra stresses set up in the outer plies as the belt bends around the pulley.

The width of pulley faces is usually made equal to the width of belt plus 2 in. for belts 12 to 30 in. wide, and width of belt plus 3 in. for belts 36 to 60 in. wide. These faces will take care of normal misalignments and belt weaving.

Tail pulleys generally have a diameter in inches equal to approximately four times the number of plies in the conveyor belt and a standard crowned face sloping $\frac{1}{8}$ in. per ft. If the maximum tension in the belt is at the tail end, this pulley should have a diameter equal to five times the number of belt plies.

In cases where the maximum belt tension is transmitted around snub, deflecting, or terminal pulleys, these auxiliary pulleys should be as large as the drive pulley; that is, 5 in. diameter per ply of belt. Other pulleys may be 3 in. per ply of belt.

The arc of contact of the belt on the head pulley should normally be 210 deg. for the average single drive. Light-duty conveyors with low belt tensions do not require snub pulleys, and the arc of contact will then be about 180 deg. The ordinary return idler should not be used as a snub pulley because of its light bearings and small diameter.

Take-ups.—Take-ups may be divided into three classes, *viz.*, horizontal gravity, vertical gravity, and screw type. Those of the gravity type are preferred because a constant tension is automatically maintained on the slack side of the belt. Wherever possible a horizontal-gravity-type take-up should be used because the cost of a vertical-type take-up is considerably more, as this type requires three additional pulley assemblies and therefore should be used only when the design of the conveyor does not permit the use of a horizontal type. On conveyors less than 200 ft. long a screw type may be used. In general, the take-up should be placed where the belt tension is low.

When designing a take-up for horizontal conveyors, the length of travel should be determined by allowing 1 per cent for belt stretch and providing travel distance on the take-up frame compensating for at least half the belt stretch. The same rule applies for inclined conveyors, except that 25 per cent greater travel distance should be provided. The amount of counter-

weight to provide should be the least with which the conveyor can be driven, as determined by an analysis of belt tensions.

Holdback.—On inclined conveyors where a reversal of the loaded belt would occur when there is a power failure, a holdback, or automatic self-locking brake, should be installed on the head shaft or countershaft, preferably on the latter to permit the use of a brake having less torque capacity.

The band-brake type of holdback is capable of giving better protection than the ratchet-wheel type, which has proved unsatisfactory because of the sudden shock caused when the pawl strikes a tooth.

Transmission of Driving Power.—Several types of transmission systems are available for the drive between the motor and head shaft. The type now used most commonly consists of a geared-head-motor speed reducer and chain drive between the low-speed shaft of the speed reducer and the head pulley shaft. The selection of this type of drive eliminates alignment difficulties which may occur in mounting the flexible coupling between the motor and an independent speed reducer and between the speed reducer and the head shaft. An added advantage lies in the fact that the conveyor speed can be conveniently increased or decreased at small cost by using various combinations of sprockets in the chain drive. The latter advantage is more appreciated in adapting the equipment from requirements on one job to those on another.

Tandem Drives.—Where it is necessary to transmit a large amount of power into a belt with considerable length or elevation, the frictional contact on the head pulley is supplemented by an auxiliary driving pulley around which the belt is passed and held in contact by a take-up or snub pulley, to develop a greater arc of contact.

Tandem drives cut down the maximum belt tension and avoid the necessity of increasing the number of belt plies or the belt width. Too many plies are objectionable because they make the belt too stiff, and extra width invites overloading the belt. Since the face of the belt in contact with the material goes around the tandem pulley, it is important to install a suitable wiper, preferably of the rotary motor-driven type, to keep the face clean.

Motors.—After the various features of mechanical and structural design have been determined, and the horsepower at the motor drive shaft has been calculated, the problem of selecting a satisfactory electric motor and its control remains.

For construction-plant work, the three-phase a.c. motor in the double squirrel-cage type (NEMA class C, high starting torque, low starting current) is the most commonly used. The wound-rotor induction motor is adaptable where definite control of starting current is necessary owing to large horsepower required, controlled acceleration, or where relatively higher starting torques are a requirement.

The difference between starting and running frictions, the inertia of the load, and the fact that grease in the various idler and mechanical bearings is usually cold at the start, all dictate a higher torque to start a loaded conveyor than is needed after the belt is up to speed. For the average conditions either a double squirrel-cage or wound-rotor motor has ample starting torque.

Motor Controls.—For across-the-line-start squirrel-cage induction motors, all the desirable features for control have been included in the standard combination fusible magnetic switch.

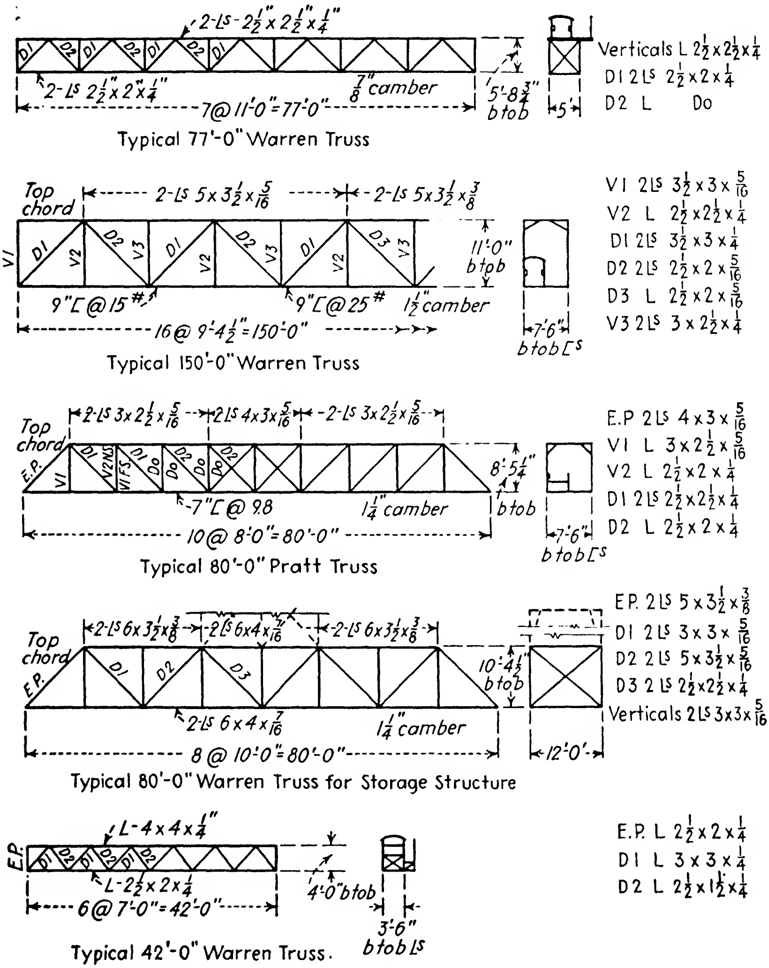
Wound-rotor induction-motor control consists essentially of two interrelated units, primary control and secondary control. For motors of small capacity, the combination magnetic switch mentioned above is used for primary control. Secondary control, which governs acceleration and speed, is accomplished by a resistor unit with either a drum controller or magnetic control panel and drum switch arranged to short out sections of the resistor unit in time steps. The subject of motors, controls, and interlocks is discussed more fully in Chap. XXVI.

Conveyor Supports.—Timber supports are good enough for most ordinary installations where no long spans are involved.

Steel structures, owing to their temporary nature, are generally designed for higher allowable stresses than given by the A.I.S.C. A minimum of three rivets or bolts should be used for main member connections and not less than two rivets or bolts for connecting secondary members and bracing.

An economic study of long steel trusses for conveyors indicates that a span length of about 80 ft. is the most economical. This length also permits the truss being shipped in two pieces.

The type of conveyor bridge may be varied. At Norris Dam, through bridges were used. All conveyor bridges were Pratt



General notes:
All conveyor stringers are 6" [s @ 8.2 # except on the 42'-0" bridges and storage structure.
All floor beams are 7" [s @ 9.8 # except on the 42'-0" bridges and storage structure.
Floor beams are at panel points

Fig. 138.—Typical design of steel trusses for belt conveyor bridges.

trusses 8 ft. high and 7 ft. 6 in. apart, with top and bottom bracing. Warren trusses 10 ft. high and 12 ft. on centers were used for the screening structures.

At Pickwick Landing Dam deck-type conveyor bridges, each consisting of Warren trusses 5 ft. 6 in. high, 5 ft. on centers, were chosen because of their lighter weight and simpler fabrication. For shorter spans the Warren truss is lighter than the Pratt truss of equal length, and fabrication is slightly easier. The deck-type truss structure is very practical and economical. A walkway and hand railing on one side of the conveyor are usually sufficient, and the conveyor itself should be covered with a series of curved plates set high enough to permit inspection of the load from the side.

Warren-type deck trusses similar to those used at Pickwick Landing and Guntersville were designed for the new conveyor bridges at Hiwassee Dam, and in order to facilitate reuse on other projects, pin bearings were adopted for these trusses.

Table 53 and Fig. 138 give general design data for conveyor trusses.

TABLE 53.—WEIGHTS OF CONVEYOR BRIDGES

DECK BRIDGES

Conveyor size, inches	Truss type	Center to center of trusses	Length of span	Depth of truss	Total weight, pounds	Weight per foot, pounds
42	Warren	5 ft. 0 in.	77 ft. 0 in.	5 ft. 6 in.	10,840	141
30	Warren	5 ft. 0 in.	77 ft. 0 in.	5 ft. 6 in.	10,700	139
24	Warren	5 ft. 0 in.	77 ft. 0 in.	5 ft. 6 in.	10,310	134
42	Pratt	7 ft. 6 in.	78 ft. 0 in.	6 ft. 6 in.	15,110	134
30	Warren	3 ft. 6 in.	42 ft. 0 in.	3 ft. 8 in.	2,600	62*
30	Warren	3 ft. 6 in.	42 ft. 0 in.	3 ft. 8 in.	3,750	90
THROUGH BRIDGES						
36	Warren	7 ft. 6 in.	150 ft. 0 in.	10 ft. 4½ in.	32,400	216
36	Warren	7 ft. 6 in.	81 ft. 0 in.	8 ft. 9 in.	13,300	164
36	Pratt	7 ft. 6 in.	80 in. 0 ft.	8 ft. 0 in.	13,500	169
30	Warren	7 ft. 6 in.	80 ft. 0 in.	8 ft. 0 in.	13,500	169
18	Warren	6 ft. 3 in.	85 ft. 0 in.	8 ft. 6 in.	14,000	165
	Warren	12 ft. 0 in.	80 ft. 0 in.	10 ft. 0 in.	23,400	292

* Welded construction.

Preliminary Design of Belt Conveyors.—For making preliminary designs and cost estimates which can later be followed

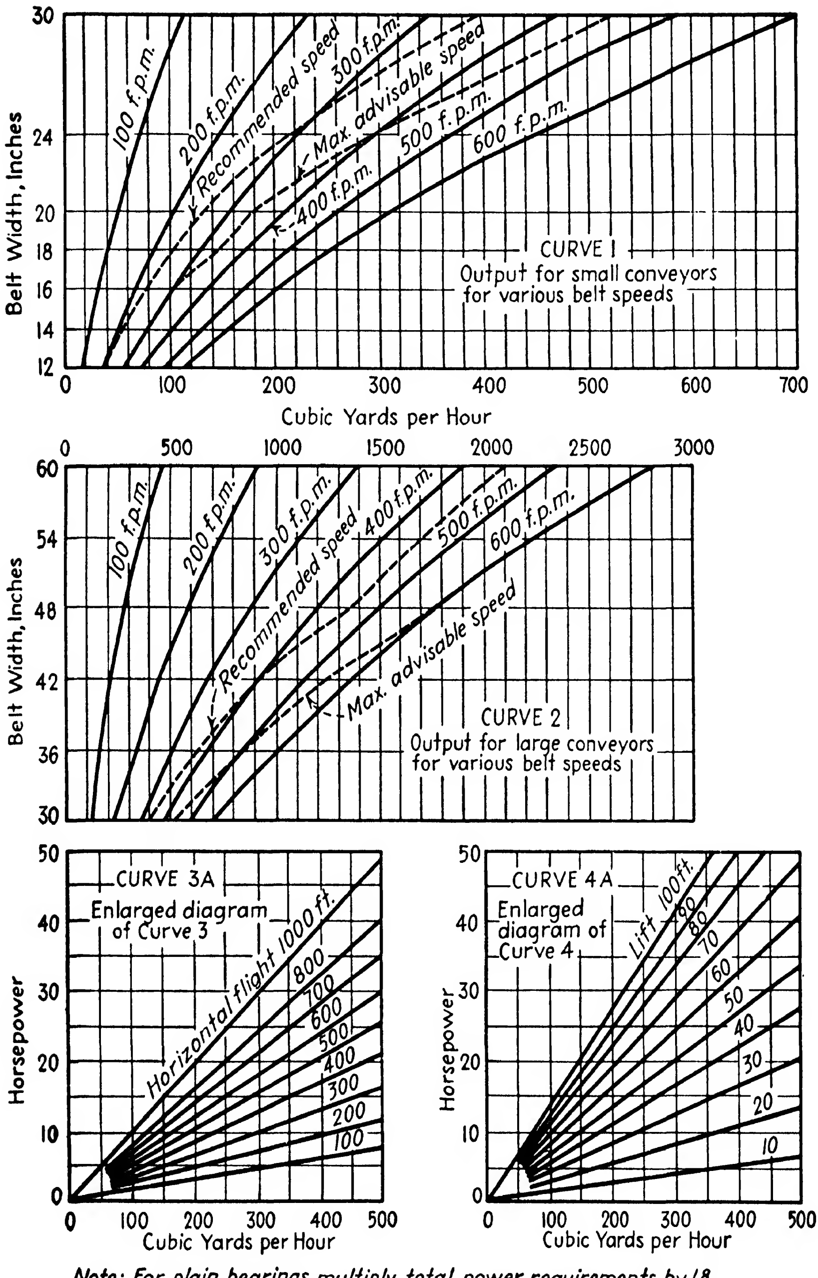
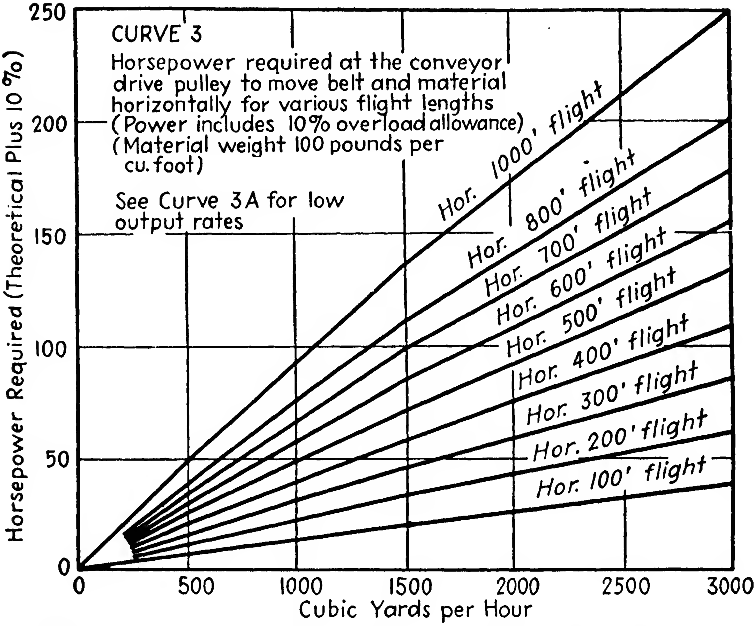


FIG. 139.—Chart I. Curves for preliminary design of belt conveyors.



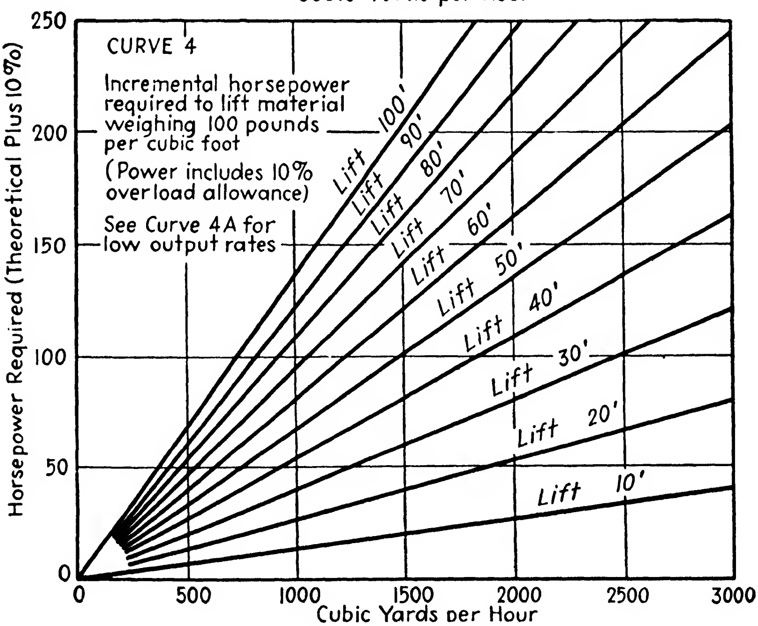
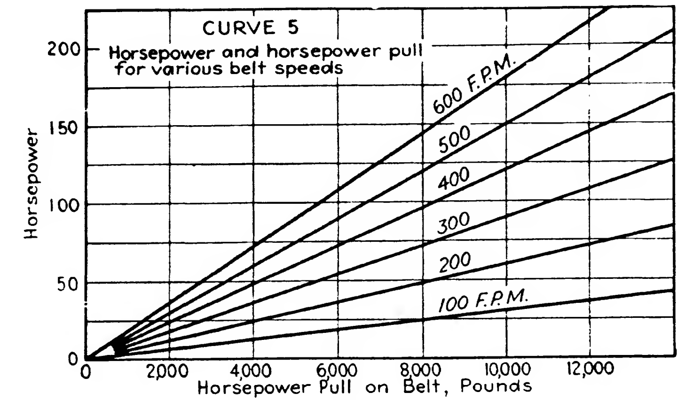
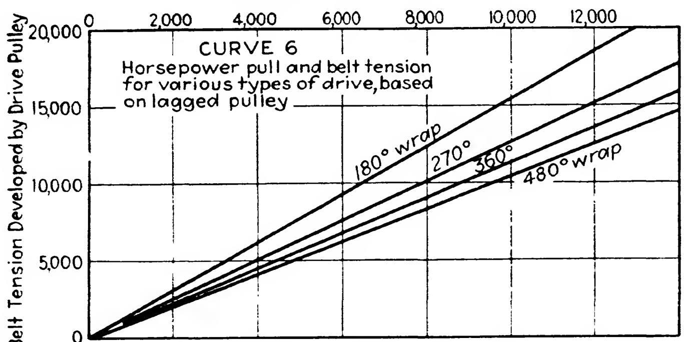


FIG. 139.—(Continued.)





* See discussion of these charts for points that fall outside of ply limits shown

EXAMPLE:—Illustrating use of data from Curves 1 to 7 inclusive

PROBLEM:—Selection of conveyor to fit following conditions:

Capacity.....675 tons/hr. of 100 lb./cu.ft. material
Length.......350 feet
Lift.........35 feet

SOLUTION:—

I Belt size and speed (Curves 1 & 2)
675 tons/hr. = 675/1.35 = 500 cu.yds/hr.
Several selections may be made from the curves.
Using only two for this example we have either a:
30" belt @ 425 f.p.m. or 36" belt @ 300 f.p.m.

II Horsepower required (Curves 3a & 4a)
To move belt and material horizontally.......... 19 (from 3a)
To lift material.................................. 24 (from 4a)
Total hp. required (with 10% overload allowance) 43
Use 50 hp. motor (next standard size larger)

III To determine belt required (Curves 5, 6 & 7)

	30" belt @ 425 f.p.m.		36" belt @ 300 f.p.m.	
Hp. pull on belt	3,900 lb.		5,500 lb	
Considering	180° wrap	270 wrap	180° wrap	270° wrap
Belt tension	6,000 lb.	5,000 lb.	8,500 lb.	7,000 lb.
Plies required	8	7	9	8

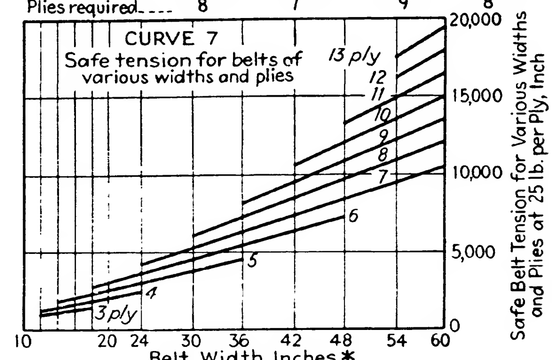


FIG. 140.—Chart II for preliminary design of belt conveyors.

by more exact analysis, if needed, two sets of curves have been assembled by Frank T. Matthias, as shown in Figs. 139 and 140. The following explanations apply to these curves:

Belt Speeds and Selection of Proper Width.

TABLE 54.—WIDTH OF BELT REQUIRED TO HANDLE MAXIMUM LUMP SIZE

Belt width, inches	Maximum lump size, inches	
	For 90 per cent of total material	Not to exceed 10 per cent of total
16	3	5
18	4	6
20	4	7
24	5	8
36	8	13
42	9	17
48	10.5	20
54	13	26
60	14	28

For width of belt required to transport the desired cubic yards per hour, see Curve 1 or Curve 2 of Chart I (Fig. 139). Using the width of belt as found from the above table as a *minimum*, select a width of belt which will transport the desired cubic yards per hour when operating within the speed limits indicated by these curves. If sharp and abrasive material is to be handled, speeds less than the indicated recommended speeds should be used to prevent excessive wear; whereas if smooth material such as river gravel is to be handled, speeds up to the maximum advisable may be used.

Horsepower Required.—For horsepower required to transport the desired cubic yards per hour, see Curves 3 and 4 of Chart I.

Add the horsepower required to move the belt and material horizontally (from Curve 3) to that required to lift the material (from Curve 4). For low capacities use Curves 3*a* and 4*a*, respectively. This total is the power required at the drive pulley. The motor should be larger by the amount of the horsepower loss in the reduction gear and to meet any requirements of standardization.

Belt Tension.—Refer to Curve 5 of Chart II (Fig. 140) to determine the "horsepower" pull on the belt (horsepower and belt speed being known).

Knowing the "horsepower" pull and the angle of wrap of the belt on the head pulley, refer to Curve 6 to obtain the belt tension.

When belt tension is a limiting factor in the design of belting, it is possible to reduce the effective tension and required number of plies by developing more than the normal 180 deg. of belt contact with the drive pulley through the use of snubbers or other drive arrangements. Snub pulleys will increase belt contact somewhat, but, if greatly increased contact is desired, a tandem-drive pulley arrangement is required. The example shown on Chart II indicates a possible reduction of one belt ply by increasing the belt-pulley contact from 180 to 270 deg. The greater contact area at the pulley produces enough friction between belt and pulley to develop the necessary driving force with very little tension in the "return" side of the belt. This reduces the maximum tension, which is the sum of "horsepower" pull and "return" side pull, to a minimum.

A 480-deg. contact will require only about two-thirds the belt tension required for 180-deg. contact at equal horsepower pull requirements. If a bare iron drive pulley is used instead of a lagged pulley, the maximum belt tension for a given horsepower pull will be increased 10 to 20 per cent, the increase being greater for the lower contact.

Belt Plies.—Knowing the belt tension and belt width, the number of plies required can be found from Curve 7.

The lower limits of belt plies shown in Curve 7 are considered necessary to prevent excessive belt wear, while the upper limits indicate a belt of maximum stiffness which will still allow proper troughing. Where the belt tension required falls above these limits, more than one flight will be required, and where it falls below the limits, the lowest number of plies indicated for that belt width should be used. Increasing the belt speed for a given handling requirement will reduce the "horsepower" pull necessary and may permit the use of fewer plies in the belt. This should be done only when absolute control of feeding is provided, as a belt at higher speeds is capable of greater output, and if loaded accordingly this produces increased belt stresses and defeats the objective.

Curve 7 is based on 28-oz. belting having a safe strength of 25 lb. per ply inch. First-quality 28-oz. belting may be stressed

up to 30 lb. per ply inch, and in this case the safe belt tensions shown in Curve 7 may be increased in proportion.

The number of plies can be determined by dividing the belt tension (from Curve 6) by the product of the allowable tension per ply inch and the belt width in inches.

Example:

Belt tension = 6,200 lbs.
Belt width = 30 in.

36-in. class A belting to be used = 30 lb. per ply per inch allowable tension.

$$\text{Plies} = \frac{6{,}200}{30 \times 30} = 6.89 = 7$$

If heavier weight belting is used, the upper limit of plies must be reduced to the point where sufficient flexibility to permit troughing is provided.

Table 29 in Chap. XV on transporting equipment gives some convenient reference data on long conveyors.

CHAPTER XXV

CANALS, TUNNELS, AND PENSTOCKS

A brief discussion covering the canal and tunnel operations on such Western projects as the All-American Canal and the Colorado River Aqueduct provides valuable information on the most up-to-date methods and equipment by which new standards of construction efficiency, speed, and economy have been attained.

Canals.—On the All-American Canal, 65,000,000 cu. yd. of sandy earth was moved by the most modern large-capacity draglines handling 12-yd. buckets on 175-ft. booms. The machines, each capable of moving 500,000 cu. yd. per month, were used primarily to excavate down to rough finished lines, or subgrades, and the final trimming was done by bulldozers and other smaller tools.

The canals of the Colorado River Aqueduct are of great interest because of the ingenuity which was displayed in their construction, and because canals of these dimensions are more frequently found in other parts of the country. The procedure there was first to make a rough cut with a dragline to within 6 or 12 in. of final grade. The sizes of the draglines on different sections of the canals varied from 2 to 6 cu. yd. Great care was taken to prevent overcutting, because the subgrade served as a base for the concrete lining and had to be stable. Final trimming was done with special trimming machines, of which those invented by Jahn & Bressi and Clyde W. Wood have advanced canal construction to a new standard of performance. Such a machine, shown in Fig. 141, has a rigid steel frame which moves forward at the rate of 1 ft. per min.—on parallel rails set to exact grade 61½ ft. apart on the canal banks—and in one operation it cuts directly to line and grade, leaving the canal ready for concrete. The digging is done by a chain of special 1-cu. ft. side-digging buckets which feed to short conveyor belts designed to dump the trimming excavation as windrows on the canal banks. The buckets travel at a rate of 28 ft. per min. and are held to exact

line and grade by rollers mounted on the chain and running in guide channels. The machine weighs about 50 tons and is propelled by a hoist mounted on the frame and reeved to a cable anchorage attached to a bulldozer which is kept spotted some distance ahead.

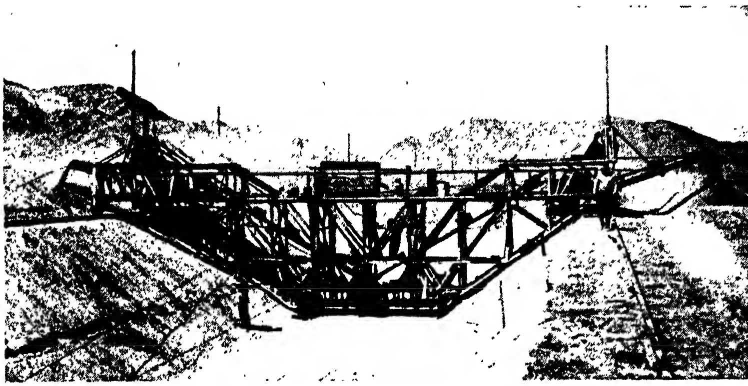


Fig. 141.—Trimming machine for finish cut on Colorado Aqueduct canal.

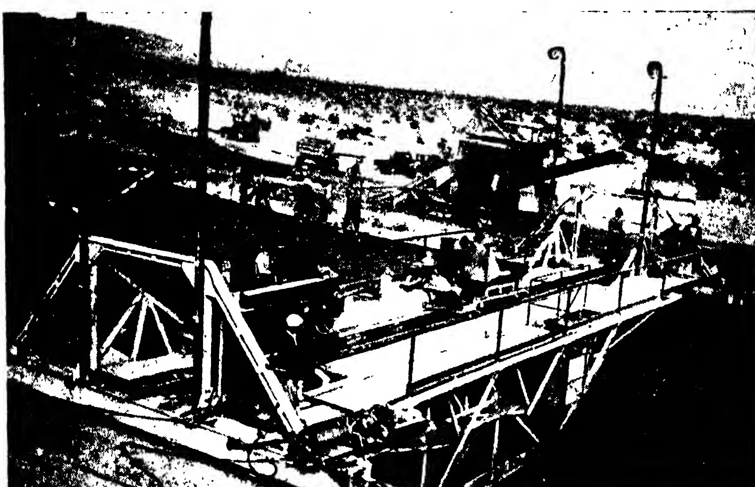


Fig. 142.—Paving machine for placing concrete canal lining.

Lining of Canals.—For placing the concrete lining, Mr. Wood developed an ingenious paver which places a 6- to 8-in. thickness of concrete in a continuous operation to exact line or grade. The paver (Fig. 142) has a wheel-mounted steel frame, similar

to that on the trimming machine, which supports a sliding steel slip form conforming to the profile of the canal lining. At the top is a runway on which a small hopper car runs forward and back with a charge of concrete and distributes the concrete as required into vertical slots which feed the concrete to the under side of the slip form. The form is equipped with tubular vibrators which compact the concrete and prevent air pockets. Two standard road-paver type of mixing units, traveling along the canal bank, charge the hopper car and the full width of the canal is placed at one time. A separate platform is mounted at the rear of the canal paver to support the men who do the hand troweling. The paver moves forward at a rate of 1 ft. per min., and up to 944 ft. of pavement were placed and finished in one 2-shift day by one machine. The average day's run was about 500 ft. of canal which required placing 700 cu. yd. of concrete.

Conduits.—Next to the canal construction, the cut-and-cover conduits are of interest. These are designed for a low head and are the equivalent of a canal with a cover over it. Most of this work is done with steel forms (Fig. 143) and traveling concrete-placing units, with the completed invert kept well in advance and the arch being placed in about 70-ft. lengths. The reinforcing steel for some of these conduits is made up in cages, in advance, to minimize the time required in setting up the forms and placing concrete. These operations became standardized into speedy and efficient routines.

Tunnel Driving.—The driving of tunnels is a highly specialized technique on which entire books have been written. It requires not only extensive experience but also a comprehensive understanding of the geologic conditions which may be encountered. If these can be properly analyzed so that preparatory work will be adequate and the correct plant selected, then the rest of the job is largely one of organization and management.

Among the older methods, the heading and bench method of mucking and drilling was considered very efficient, because drilling could proceed on the heading while the bench was being mucked, and there was greater continuity of operation in both procedures. Another early method which was considered almost standard, particularly in the larger tunnels, consisted of first driving a pilot tunnel and enlarging later after the pilot was completed. Both of these methods have been displaced in the

most recent projects by the full heading method of intermittent driving and mucking, and this procedure has generally been found to be more efficient and economical on long tunnels.

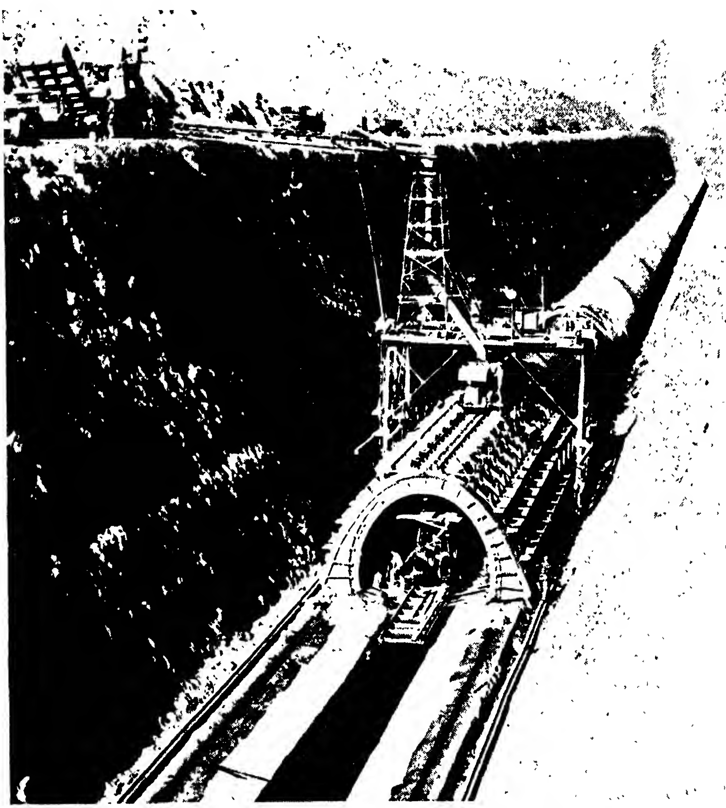


FIG. 143.—Traveling arch form and concrete placing plant on Colorado Aqueduct cut-and-cover conduit.

On a simple, dry tunnel job the rate of progress is essentially a function of the size of the tunnel and location of the portals. The nature of the rock, of course, is of primary concern, and if there is a tendency for considerable overbreak the yardage may become substantially greater than was originally estimated. Where the portals are far apart and it is necessary to increase the speed of driving, the tunnel is attacked at a number of other points through vertical shafts or side adits, if these can be reasonably short or, in rare cases, a smaller parallel pioneer

bore, about 10 by 10 ft. square, is driven alongside the main tunnel location, through which the main tunnel can be attacked from various points. Such pioneer bores also have a special utility value in handling ventilation and drainage.

The great number of different contracts on the Colorado River Aqueduct and the large amount of tunneling done on that project

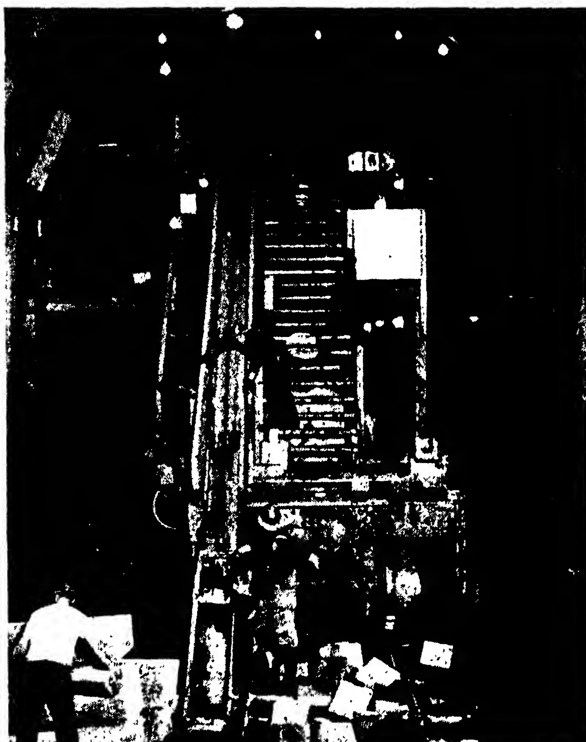


FIG. 144.—Back side of drill carriage designed for standard-gauge track. Side platforms fold down.

have provided a testing ground for different methods and ideas which have finally been worked down to rather standardized procedures, representing notable advances in equipment and methods. Most of the tunnels are 18 ft. in diameter and were excavated by the full-face heading method.

Drilling and Mucking.—For drilling, heavy drills were employed, with power feeds and independent drill rotation. The drills were mounted on special portable carriage assemblies

or "jumbos," similar to Fig. 144, which allowed more drills to be put into service on the full face promptly after mucking had been completed. The portable drill carriage eliminated the need for scaffolding and loss of time incident to setting up. Four to six drills (Fig. 145), were used and they drilled the 25 to 60 holes 6 to 12 ft. deep required per round in from 2 to 3½ hr. For a single heading about 1,500 cu. ft. per minute of air was required for drilling, the air being delivered from the com-

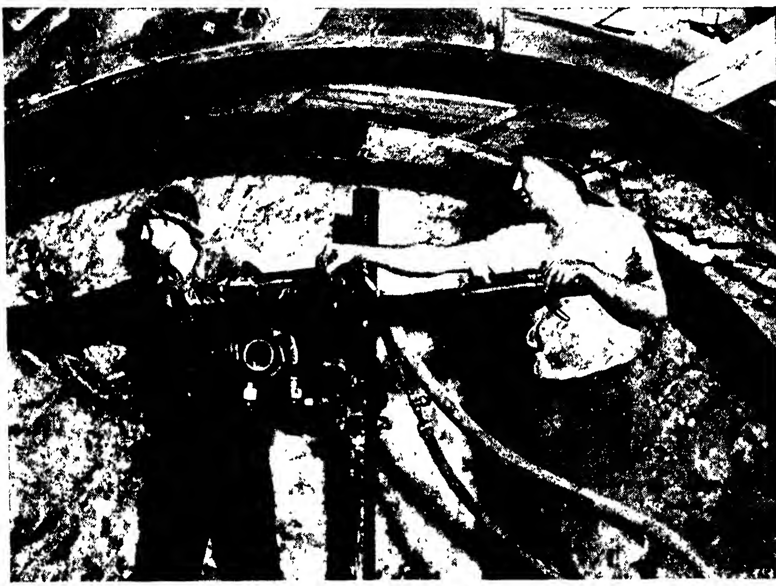


FIG. 145.—Drifter drill with carriage mounting.

pressor house at the audit through 6-in. pipe. The drill shops, also located at the adits, were usually equipped with modern forging and automatic tempering machines.

As a rule, 25 to 40 per cent dynamite was used, which averaged about 3½ lb. per cu. yd. of solid rock. The job of handling the explosives, including storing, protection against freezing, and proper layout of shots and firing diagrams, requires special knowledge and experience. Some small shovels were used for mucking, but a tunnel 18 ft. in diameter is somewhat tight for a tunnel shovel, and in all but 3 of the 54 headings Conway muckers, a combination loader and short conveyor unit (Fig. 146), were employed. Where it formerly took 8 hr. to clean out a

10-ft. round, only 2½ hr. were required on the average for this operation.

In rock formations where there is even a slight danger of encountering water-bearing seams, it is advisable to carry one drill hole about 30 ft. ahead to tap such seams and promptly seal them by pumping in grout under pressure through the drill hole. If this is not done before blasting out the heading, it is very difficult and time-consuming to stop the water.

FIG. 146.—Conway Tunnel mucking machine.

Hauling of Muck.—Most transportation of muck was by electric-storage-battery locomotives (Fig. 147) of 6 to 8 tons capacity, or combination battery and trolley locomotives. They hauled from 6 to 8 cars per train, the cars having capacities of 4 to 6 cu. yd. The better ones were of steel and equipped with roller-bearing wheels. The use of Diesel locomotives in tunnels, since the exhaust is free from CO gas, is likely to become an important innovation in economical tunneling practice of the future.

One of the most important operations to assure rapid transportation and a minimum loss of time is efficient car switching.

It is important to have an empty car "standing by" as near as possible to the mucking machine and to remove the loaded cars promptly. One of the early devices for interchanging cars was known as a "cherry picker," which lifted an empty car off the track and moved it up or sidewise so that the loaded car could be pulled out and the empty set adjacent to the mucker. The "cherry picker" consists of a small air-operated or electric hoist mounted on a movable gantry frame, which is shifted as necessary in handling the cars. Another device, somewhat more

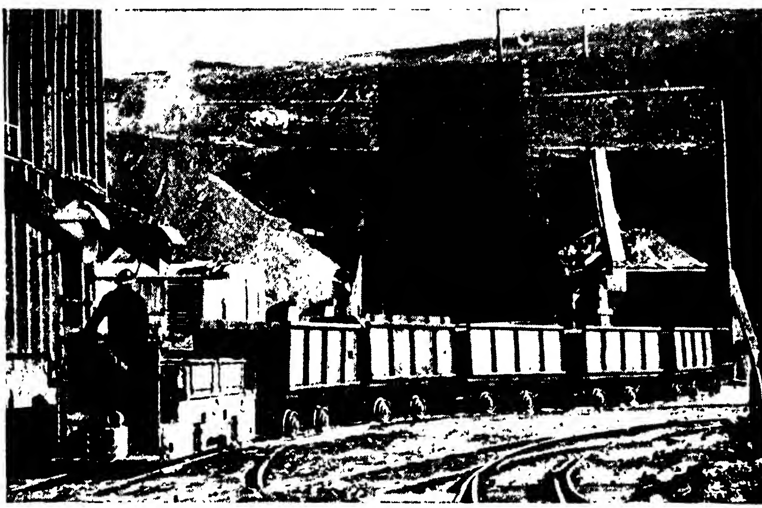


FIG. 147.—Storage-battery locomotive and side-dumping muck cars.

elaborate, is known as the "grasshopper," which is a long truss frame on which the empties are stored in an overhead track and the loaded cars pass out underneath, the empties moving forward and down a short ramp to the mucker as required. One of the best devices, especially popular on the Colorado River Aqueduct, was known as the California switch. It consists of a short double-track assembly, completely welded into a unit with frogs and switches, and this slides along the top of the single main track. The ends of the rails are tapered to fit the main track so that cars can travel over the California switch and to and from the main track without difficulty. This switch is kept close behind the mucker; on one side the loaded cars are passed out while empties promptly move forward to the mucker from the other siding.

One of the more novel developments in car-loading methods is known as the Dixon conveyor, which consists of a long belt elevated sufficiently to allow a complete train to be stored under the belt, and the cars move forward as they are loaded. The belt itself is loaded by a standard Conway mucker. The front

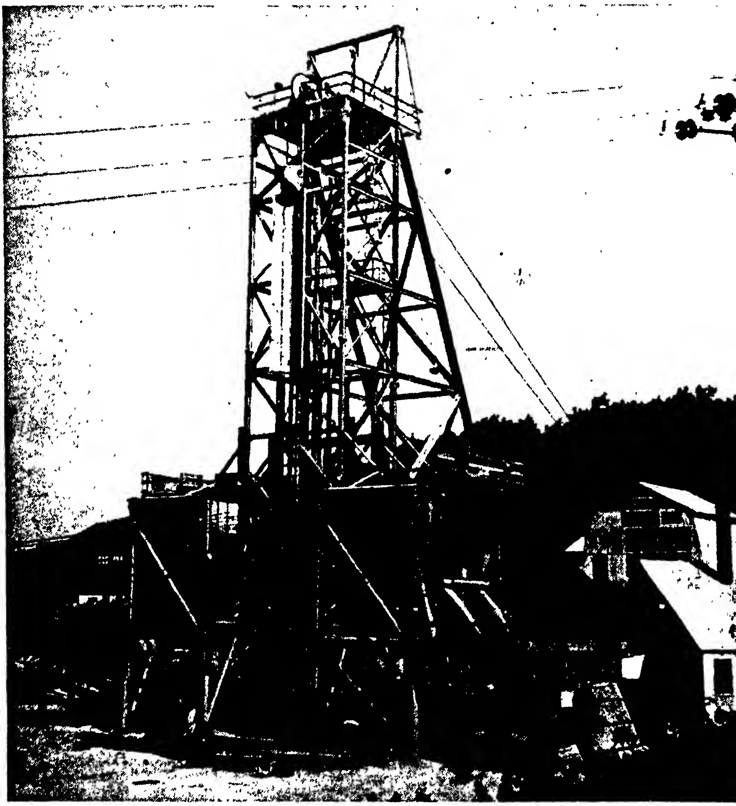


FIG. 148.—Headframe and muck bins on Delaware Aqueduct shaft. Hoist house in back ground.

end of this conveyor unit is also equipped with a drill carriage, and by thus combining the carriage with the mucking unit, the loss of time due to interchange of units is eliminated. It seems best suited to "dead" rock which does not fly very far or produce a lot of random mucking. This conveyor, like the grasshopper and certain types of cherry picker, requires an extra set of tracks. On the Delaware River Aqueduct the majority of the contractors chose the cherry picker as the simplest and safest

car-transfer device. A number of these were designed to travel on the main haulage track, as were also the drill carriages, thus making it possible to carry only one track forward with the heading. The second track with wide gauge for certain types of cherry picker or drill "jumbo" is, however, very useful in getting the "jumbo" to the heading quickly to resume drilling.

In removing muck through short vertical shafts it is customary to lift the cars and dump them at the top, whereas in deep shafts the cars do not come to the surface but are dumped through a hopper, and the muck drops into skips which are hoisted to the surface where they discharge into steel bins. From here it is loaded into trucks for disposal. On the Delaware River Aqueduct with shafts 400 to 1,200 ft. deep the shaft, headframe (Fig. 148) and hoisting equipment was in each case a major plant item involving important engineering problems and heavy investments. A typical large hoist with a 10-yd. skip and large cage above the skip handled a total load of 60,000 lb. on a single drum 8 ft. in diameter by 10 ft. long with a 2⅛-in. cable. A second cable ran to a 40,000-lb. counterweight. A 600-hp., 720-r.p.m. motor with double reduction herringbone gears developed a hoisting speed of 750 ft. per min.

Ventilation and Drainage.—A standard item required in a tunneling layout is the ventilating system. On the Colorado aqueduct, about 10 to 15 min. were required to clear the heading of smoke. This was done with a reversible air system which sucked out the smoke and then blew in fresh air through a 22-in. metal vent pipe which was carefully gasketed to prevent leakage. On the Delaware River Aqueduct air was supplied to each heading at the rate of 10,000 cu. ft. per min.

Ventilating ducts of the collapsible canvas type are especially useful near the headings where they can be readily dismantled and erected depending upon blasting conditions.

An item which sometimes assumes most serious proportions when ground water is encountered is the problem of drainage. This may lead to construction of separate pumping chambers or even parallel pilot tunnels located at a somewhat lower elevation so that the drainage of the main tunnel can be diverted or pumped out.

Tunnel-driving Progress.—Table 55 gives representative performances on some of the Colorado River Aqueduct tunnels

which in general are 18 ft. in diameter. An excellent summary of experiences on this project was given by Burkholder and Stephens in "Hard Rock Tunneling" in *Civil Engineering*, April, 1939.

The first seven tunnels were largely excavated in the dry, through broken rock, and about 63 per cent of the length required timbering or steel supports. This work was all done under contract. The Valverde Tunnel encountered considerable water and unstable formations, and the remaining four tunnels here listed also encountered some water, the San Jacinto providing the most difficult conditions. These last four tunnels were done by day labor. The over-all average rate of tunnel driving on the dry headings has been about 7 ft. per 8-hr. shift, at a cost of $3.90 per cu. yd., and on the wet headings 3 ft. per 8-hr. shift.

TABLE 55.—COLORADO RIVER AQUEDUCT

Section of Aqueduct	Length, feet	Contract price, per foot	All headings: Best day's progress, feet	All headings: Best month's progress, feet	Average length excavated per month, feet
1. Copper Basin No. 1...	705	$97.00	30	649	588
2. Copper Basin No. 2...	11,570	97.00	54	1,084	656
3. Whipple Mountain....	32,240	81.00	55	989	693
4. Iron Mountain, East..	23,645	94.00	40	747	474
5. Iron Mountain, West..	16,200	105.00	47	1,027	664
6. Coxcomb............	17,800	91.00	38	741	612
7. Cottonwood..........	20,100	92.00	45	923	609
8. Valverde.............	38,000	84.00	36	595	249
9. East Coachella.......	96,600	81.00	48	843	548
10. 1,000 Palms No. 1....	16,050	81.00	51	1,101	543
11. Seven Palms.........	16,730	81.00	54	942	600
12. San Jacinto..........	68,850	242.00	43	767	165

Progress on Delaware Water-supply Tunnels.—Further outstanding progress in tunnel construction is being made on the Delaware Aqueduct as reported by the New York Water Bureau. At Shaft 22 where the finished diameter is 19½ ft. in hard rock,

the average progress on 5,000 ft. was 480 ft. per month in one heading with a maximum progress of 636 ft. per month. This was made with a full-face operation using 70 to 75 holes and 60 per cent dynamite in amount of 3.8 lb. per cu. yd. of material blasted. Nine drills were used to drill these holes, using 2½ to 3 hr. for drilling, 30 to 40 min. to clear the smoke out of the heading, and 3½ to 4½ hr. to do the mucking. At Shafts 4 and 5 where the tunneling is in shale which drills easy and breaks well, some remarkable progress was made. The finished tunnel here is 13½ ft. in diameter (18 ft. rock diameter). Typical progress is 250 ft. per week in each heading or better than 1,000 ft. per month.

Lining of Tunnels.—In broken rock it is necessary to erect temporary supports, of either timber, steel, or steel ribs lagged with wood, and the concrete lining is later placed directly against the temporary supports. Steel forms have almost become standard for placing concrete lining, Fig. 149, because they are more economical for repeated use under uniform conditions, and they produce a smooth concrete surface. One of the various types operates with a traveling carriage designed to carry sections of a collapsible form; when collapsed, the form may be transported through a section of form which is in service for reerection and subsequent filling. Another very satisfactory system consists of a series of forms making up a section about 120 ft. long, which, after filling and setting, is collapsed and the full length moved forward and made ready for the next filling. This works out well where the standard routine permits moving and setting the form on the first shift, filling on the second shift, and concrete setting on the third shift.

On some of the 10-ft. distribution conduits of the Colorado River Aqueduct a group of 14 circular steel panel forms, each 5 ft. long and hinged for collapse, were employed. These were mounted on a traveling truss 160 ft. long by 5 ft. deep. Each collapsed form was supported on jacks and rollers and could be moved forward on the truss. This type, known as the Hackley type, is particularly suited to work on curves. The reinforcing steel for this lining was brought in straight to the site of concrete placement and bent there. This procedure was found to be more economical than to handle the cumbersome curved pieces through a long tunnel.

The Colorado Aqueduct tunnels have a minimum thickness of 9 in. of concrete at the crown and 6 in. on the side. On some operations, 100 ft. of forms were set up at one time and placing was more or less continuous. No special construction joints were provided, the front of the concrete merely sloping off in a

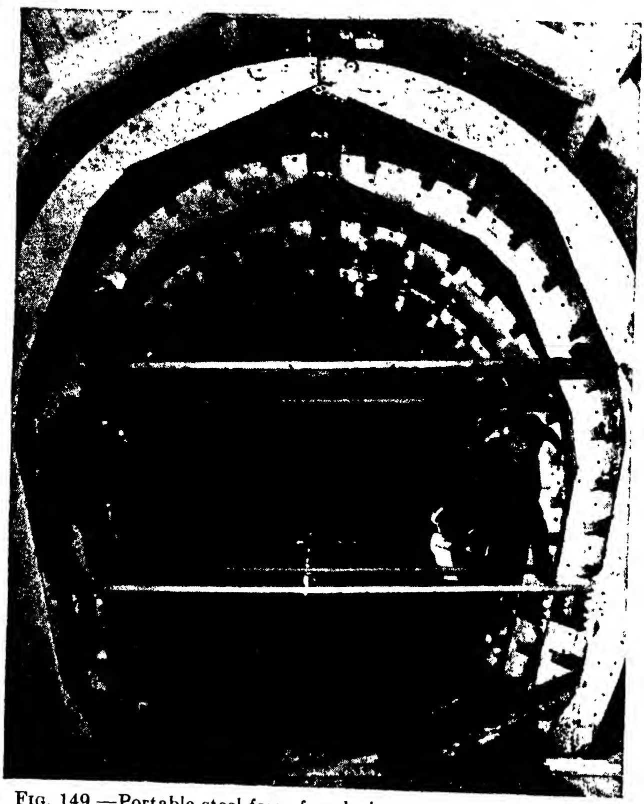


FIG. 149.—Portable steel form for placing concrete tunnel lining.

distance of 60 to 90 ft. The steel forms weighed about 1,200 lb. per ft. and were equipped with side manholes through which concrete in the side walls could be delivered and inspections made. They were stripped 8 to 10 hr. after the last concrete was placed. The sequence of placing tunnel lining was generally as follows: first, small curbs on each side, which provides a base for alignment and support for the form carriers; second, the arch; finally, the invert, after cleanup and removal of all pipes,

wires, and tracks. Where the arch and invert are carried forward within 100 or 200 ft. of each other, the invert always provides a place to work when there is trouble with the arch-lining equipment or serves as a "fill-in" job when the arch placing operation is completed before the end of the shift.

The aggregate was batched dry in a central plant at the tunnel portal and hauled in batch cars for mixing at the point of use. Placement was by means of concrete pumps (Fig. 150), or pneumatic placers (Fig. 151). The latter are simple and low in first cost, but the pump, a comparatively modern development, has proved satisfactory and can handle a drier concrete.

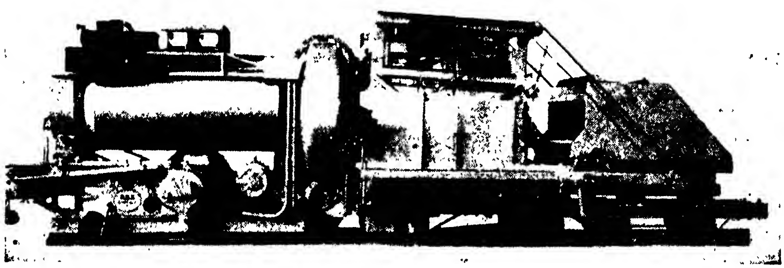


FIG. 150.—Combination concrete pump, agitator, mixer, and charging hopper for placing tunnel lining.

The pipe line which carries the concrete is located in the top of the arch form, and the concrete slides down the sides. The placing machine and pipe move forward as the form is filled, but the discharge end is allowed to remain embedded a short distance in the concrete at the crown and is sometimes moved forward and backward to insure better packing and placement in the rock irregularities. The high air pressure used with pneumatic placers helps to fill the irregularities. Further to assure the filling of voids and possible air pockets at the crown, heavy pressure grouting was applied to the completed lining.

One plant placed as high as 2,280 ft. of arch in one week. A total of 12,220 ft. of invert was placed by one plant in 1 week, using a special paver unit.

Equipment for Placing Tunnel Lining.—The Hackley concrete placer operates by air pressure and has the advantage of employing no mechanical parts subject to heavy wear. It consists of an ejector chamber with a capacity of ½, ¾, 1, 1½, 2, or 3 cu. yd.

This is filled with concrete and then compressed air is applied through a specially arranged set of pipes which propels the concrete forward into a 6- or 8-in. transport line; from 40 to 60 sec. are required to empty the ejector. As a rule the placer is set in a gantry crane (Fig. 151) to one side so that the muck cars from the heading will readily pass. The best conveying distance for this equipment is 80 to 140 ft., and 2 in. is about the maximum size of stone for this equipment. The 1-yd. machine requires about 1,000 cu. ft. per min. of air. On the Colorado Aqueduct the 2-yd. machine placed about 900 cu. yd. in 24 hr.

Another type of pneumatic placer which has proved efficient and fairly economical on air is known as the Press-Weld concrete placer, which operates on 60- to 80-lb. air pressure.

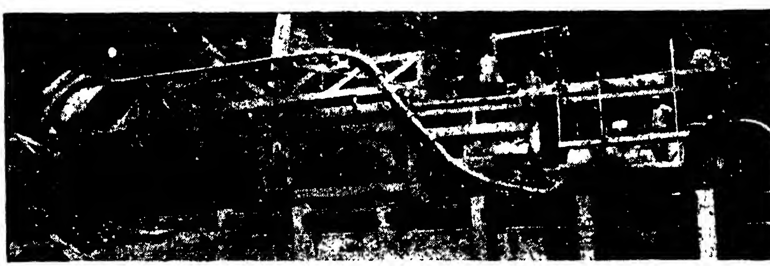


FIG. 151.—Pneumatic concrete-placing gun and discharge pipe to form.

The Ransome pneumatic placer has a motor-driven spiral screw to propel the concrete forward into the pneumatic chamber where the air is applied to drive it through the transport lines.

Among recent improvements in pneumatic placing equipment is the use of special alloys and replaceable plates at the wearing points, and the introduction of long-radius bends in the transport lines. As a rule, 10,000 cu. yd. of concrete can be handled before replacements are necessary.

The most recent development in concrete-lining methods has been the application of the Pumpcrete machine for tunnel work. On the Colorado River Aqueduct, eight machines were employed, using 7- or 8-in. delivery pipes. (This machine was described in Chap. XXII, the main feature being a direct ram which propels the concrete forward.)

The Pumpcrete placing units, in combination with mixers, received dry batches of concrete from a central batching plant located at the portal. The material was hauled in special batch

cars, a train usually consisting of 10 cars containing 30 batches. In addition to the direct pumping action, air at about 100 lb. was supplied to the discharge end, which helped to ram the concrete into the arch. Best progress with a one-cylinder unit of 1-yd. capacity was 16,300 yd. in 1 month, or 188 lin. ft. of 18-ft. tunnel arch per three 8-hr. shifts. This was equivalent to 629 cu. yd. per day. On another heading a two-cylinder unit in its best month placed 23,900 yd. of concrete or 885 yd. per day of three 8-hr. shifts. A total of 103 men, including superintendents, made up the organization for three shifts; this included the men working in the shop, at the pit, in the batching plant, and in the placement crews.

On one of the Minneapolis sewer tunnels a special arrangement of the Pumpcrete unit was employed. This consisted of a pump set up on the ground, with concrete delivered through well holes to the tunnel, located a short distance below the surface. The tunnel varied in size from 3 by 6 ft. to 10 by 10 ft., and the ability to adapt this arrangement of Pumpcrete to different sizes of tunnels was a particular advantage.

The Montebello Tunnel (Fig. 150) Pumpcrete unit was made up of a mixer car weighing 18,000 lb., capacity 1½ yd., and a pump car weighing 16,000 lb., with a single-cylinder pump and a remixing drum. A fleet of 15 batch cars, each holding two 1¼-yd. dry batches, served the mixer and pump units; batches dropped from ground surface through pipes in the shaft to carloading bins.

Shield Tunneling.—Some of the most difficult problems in construction are encountered in driving a tunnel shield through subaqueous formations of earth or loose material. The operations are highly specialized and require a great deal of knowledge and experience. The present high state of efficiency in shield tunneling has been attained through expert organization, coordination of the individual steps, and ingenious plant layout. Among the most recent examples are the Lincoln Tunnel under the Hudson River in New York, and a Detroit sewer tunnel. This highly specialized field was discussed in a valuable paper "Subaqueous Tunnel Construction" by H. L. King in *Civil Engineering*, March, 1939.

On the Lincoln Tunnel, which is 31 ft. outside diameter, the tunneling was done by the silt-displacement method, under

which 75 to 80 per cent of the silt was pushed aside and only enough of the core was passed through the shield to serve as ballast against flotation of the tube. The shield was 31 ft. 8 in. in outside diameter by 18 ft. 10 in. long, and weighed about 310 tons. The advancing face of the shield was closed off completely except for two bulkhead gates, 2 ft. 4 in. square, through which silt was admitted as the shield was shoved forward by the action of twenty-eight 10-in. hydraulic jacks mounted on its periphery and pressing against the front edge of the cast-iron lining assembled immediately behind the shield. The shield had a cast-iron cutting edge and special working platforms whose elevation was hydraulically controlled. Several short sections of belt conveyor located just behind the bulkhead gates deposited the silt beyond the shield onto the completed section of cast-iron lining.

A special mechanical erector arm handled the cast-iron liner segments, which are 30 in. wide and of which fourteen were required per ring. As the rate of progress was not controlled by the mucking but by the bolting of the cast-iron segments, a special type of hydraulic bolt tightener was developed to speed up this operation. Four units worked on a ring at one time. This tightener constitutes a major advance for this class of equipment. There are 2,360 cast-iron segments in the tunnel, weighing 51,800 tons and requiring 346,000 bolts, 1¾ by 8¼ in., for the assembling. A diagram of the shield is shown in Fig. 152. A gang working on a heading consisted of 35 men and they worked in 16 to 18 lb. of air.

On the Lincoln Tunnel, 5,060 ft. were driven in 7 months, a record of 1,040 ft. being made in 1 month of 24 days. An average daily shift drove about 40 ft. in 24 hr. In comparison with this, the Holland Tunnel record was 555 ft. in 1 month and 25 ft. in 1 day.

On the Detroit sewer tunnel, which was 22 ft. in diameter, 50 ft. was driven in a 20-hr. day. In this case practically all of the muck was taken through the shield through six 2- by 2-ft. openings in the bulkheads, the driving being through a soft blue clay under air pressure. One shove delivered about 40 muck carloads of clay into the tunnel. The shield was 15 ft. long and equipped with twenty 10-in. jacks. Instead of a cast-iron lining, there was a primary lining of interlocking concrete blocks 18 in.

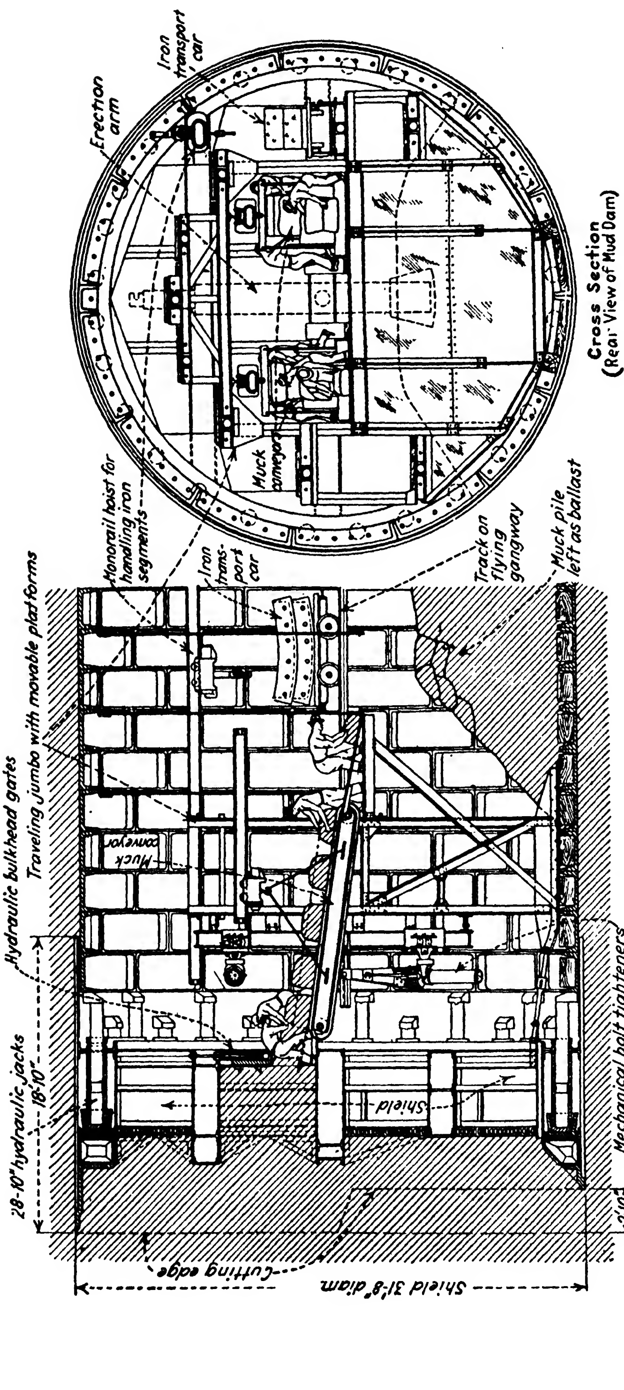


FIG. 152.—Shield for driving subaqueous tunnel through silt.

thick and 30 in. wide, which were handled by a special rotating placing arm. The final lining was a 16-in. concrete inner lining constructed monolithically by standard tunnel lining methods at a rate of 50 ft. per day. The handling of the muck out of the tunnel was a major problem here, and a special roll-over dumper was used at the unloading point to remove the sticky material and to expedite the handling of cars.

Concrete Pipe.—The erection of special precast concrete pipe of large diameter has reached new forms of application on the Colorado River Aqueduct, where sections 12 ft. in diameter and 12 ft. long, each weighing 40 tons, have been installed. The precasting of pipe sections in special well-equipped yards was handled by systematic methods. The reinforcing cages were made up in advance and set into steel inner and outer forms, after which the concrete was placed and vibrated for compaction.

The reinforcing, instead of being made up from individual hoops, was rolled on large-diameter mandrels from continuous rods. The completed sections of pipe were painted with a coal tar to retain the moisture and prevent too rapid drying and curing and were later transferred on special heavy-duty trailers. In the level sections of the pipe line a heavy derrick straddling the trench lifted the pipe from the trailers into place in the trench. On inclines the sections were hauled up on special railroad trucks and skidded to place on steel rails which were set to line and grade, after which a continuous concrete cradle was poured under the assembled line before final backfill was placed. The design of the pipe is standard, but the joints are of special importance to assure both continuity of the structural pipe line as well as watertightness.

Penstocks.—The Bouquet Canyon pipe line in California, which was placed over exceptionally rough terrain and on steep slopes, represents one of the recent developments in modern all-welded penstocks. It is 90 in. in diameter and designed for a maximum head of 820 ft., or 400 lb. per sq. in. The thickness of plates varies from $\frac{3}{8}$ to $\frac{13}{16}$ in. The sections weighed about 10 to 12 tons and were carried by a "straddle bug" carrier running on rails which straddled the penstock line. The individual sections of pipe were lowered with an electric hoist.

At Norris Dam a special penstock fabricating plant was erected near the dam (Fig. 153) and the bent plates were received from the shop and assembled here by electric welding. The field

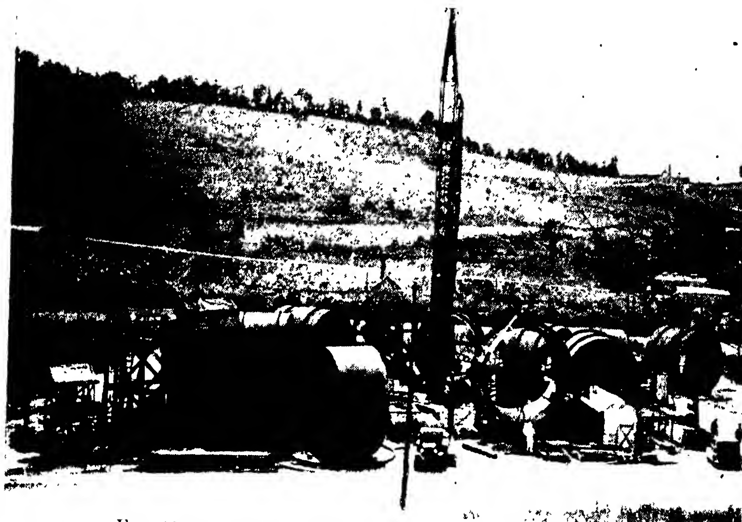


FIG. 153.—Circular layout of penstock fabricating yard.

plant included special X-ray and stress-relieving equipment. The completed sections were delivered to the dam on a heavy-duty trailer and transferred into place by cableways.

CHAPTER XXVI

ELECTRIC POWER AND EQUIPMENT

In recent years the use of electricity on large construction projects has developed to such an extent that many large jobs are now considered completely electrified; stationary steam, Diesel, or gasoline prime movers are used only for secondary

FIG. 154.—Electric-power substation for a large job.

or isolated services. Consequently, the electrical engineering of a construction plant is of great importance. Adequate advance planning and attention to detail are required to develop the most economical power and distribution system and to assure maximum reliability and freedom from interruption at any point in the electrical system.

The great variety and sometimes intermittent operation of construction equipment introduce severe electrical disturbances, such as high peaks of short duration, unavoidable surges, and short circuits. Therefore, the incoming transmission line, the substation, and the plant distribution system should be designed

with liberal capacity and with special consideration to ruggedness, simplicity, and adequate electrical protective features even though the entire system may be considered as a temporary facility.

Distribution System.—A good example of a carefully planned electrical system is the one designed by T. N. Whitehouse for the Hiwassee Dam, which is here described.

The power lines from the low-tension side of the main transformers (Fig. 154) are connected to the plant distribution switchboard, consisting of ten 2,300-volt panels. Panel No. 1 is a 2,000-amp. transformer incoming panel. The other nine panels are 600-amp. feeder panels for nine separate circuits leading to various points of the construction and camp area so that interruptions in any one circuit are isolated and do not ordinarily affect operations in the rest of the area (see one-line diagram, Fig. 155).

Each circuit is provided with protective equipment and watt-hour meters. The incoming panel No. 1 is equipped with the following:

Manual 2,000-amp. oil circuit breaker
Three disconnecting switches, 7,500 volts
Voltmeters, single phase with scale reading 0 to 3,000
Voltmeter transfer switch, three phase
Ammeter, 0 to 2,000 scale, single phase
Ammeter transfer switch, three phase
Power-factor indicator, 0.5-1-0.5 scale, three-phase
Recording wattmeter, 0 to 1,000 watt scale
Recording wattmeter transfer switch
Watt-hour meter, three phase
Test block
Potential transformers for metering
Current transformers for metering and oil-circuit-breaker tripping

The graphic recording wattmeter is so arranged that it can be plugged into any one circuit for studying power requirements and plant efficiency. Portable recording wattmeters are used to supplement these studies on individual equipment.

Each feeder panel contains the following:

Manual 600-amp. oil circuit breaker
Three disconnecting switches, 7,500 volts

Ammeters, 0 to 600, single phase
Ammeter transfer switch, three-phase
Recording wattmeter transfer switch
Watt-hour meter
Potential transformers for metering
Current transformers for metering and oil-circuit-breaker tripping

The construction-plant distribution circuits are laid out for maximum flexibility since many items of equipment, such as electric shovels, pumps, drills, welders, etc., must be shifted to new positions on short notice. Practically all motors above 50 hp. are 2,300 volts, with a few exceptions such as cofferdam pumps; smaller motors, except built-in and portable tool motors, are operated from 440-volt lines. Most of the motors driving shop equipment located in various construction-plant buildings are rated for operation from 220-volt supply. It is especially important to keep the voltage on cofferdam pumps down to prevent accidents to men who are sometimes obliged to handle them in emergencies without shutting off the power.

Distribution transformers are located on the borders of the main work area to prevent interference with hauling equipment and to keep them out of danger from blasting. The transformer banks are generally kept down to capacities of 300 to 500 kva. to facilitate moving on short notice. It is highly desirable to keep the number of different sizes of transformers at a minimum to simplify interchanging and shifting, even at the expense of occasional low-efficiency operation. For traveling equipment such as cranes, shovels, or hoists, open trolley wires with power pickups should be avoided. Heavy-duty submarine cable is far more dependable and safer even for 2,300-volt circuits.

Construction-camp circuits, when fed from the same substation as the power circuits, should always be isolated from circuits supplying power to plant equipment, and it is desirable that they be protected by reclosing-type circuit breakers.

Figure 155 also gives the load requirements for Hiwassee Dam. As a further indication of loads on such projects, the following is taken from Norris Dam, where the total connected load was 6,500 kva. The maximum registered peak was 4,100 kva., while the annual average peak was 3,540 kva. The annual consumption was 15,738,000 kw.-hr. The total connected load at

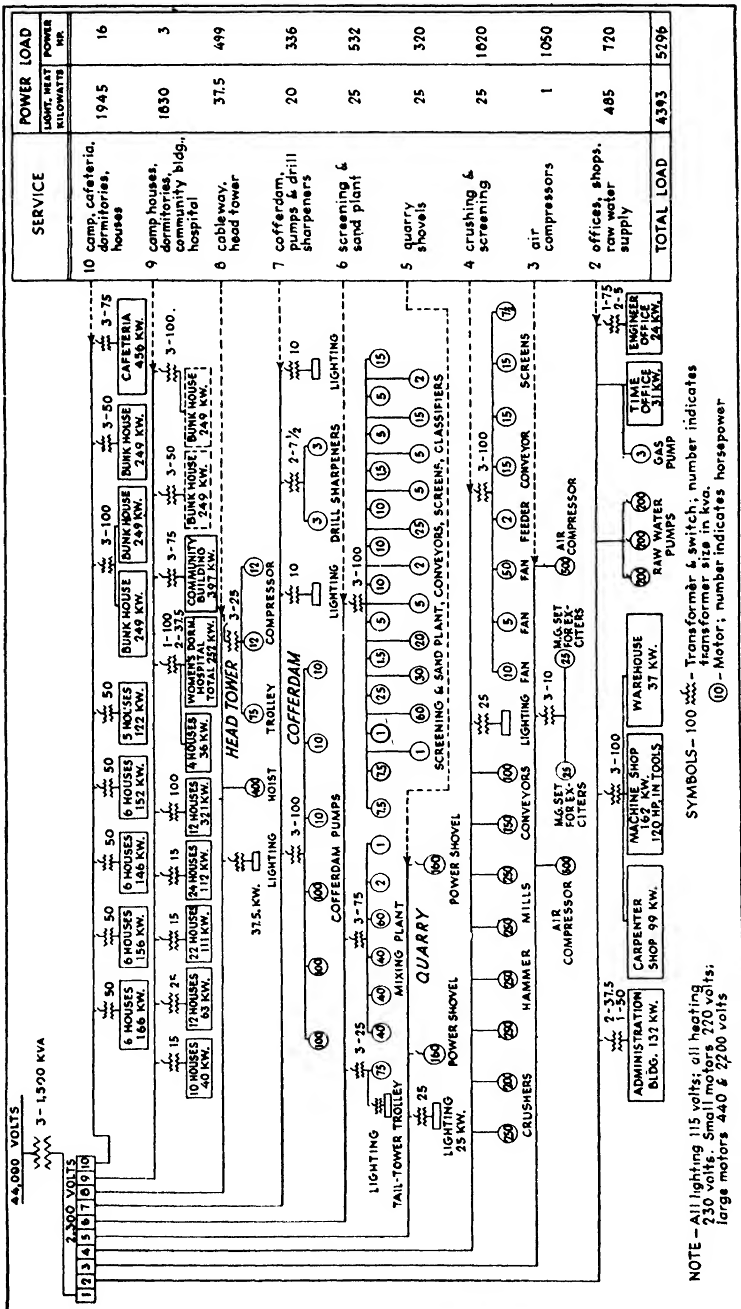


FIG. 155.—One-line diagram of load requirements for Hiwassee Dam construction plant.

the town of Norris was 6,500 kva. The maximum registered peak was 2,524 kva., while the average annual peak was 1,704 kva. The annual consumption was 4,854,000 kv.-hr. Both of the foregoing loads were fed from one 2,500-kva. and one 1,500-kva. three-phase transformer.

Selection of Motors.—The selection of motors for a construction project involves consideration of the required load characteristics such as operating torques, constant or variable speed, reversing or nonreversing, and continuous or intermittent duty. Each motor should be interchangeable with other similar equipment, and its control should be simple and free from unnecessary automatic features. Table 56 gives the representative types of motors and their general application to various types of construction equipment.

Alternating-current motors are available in single-phase or polyphase types. Polyphase motors, classified generally as induction or synchronous, are most commonly applied to construction work, while the single-phase motors have relatively few applications except for small tools, fans, vibrators, and other equipment requiring low power. Induction motors are of two types, squirrel cage and wound rotor. The squirrel-cage motor is best adapted for all classes of constant-speed service where infrequent and moderate starting and running torques are required. The wound-rotor motor (Fig. 156), on the other hand, is used for frequent starting duty and provides high or moderate starting torque with low input current. By using collector rings and external rotor resistance, this type of motor is readily adapted to various types of service requiring variable-speed control over a wide range, as on hoists and similar equipment.

The synchronous motor, operating at a constant synchronous speed, is available generally in two types, one providing unity power factor and the other 80 per cent leading power factor. Because of its value for power-factor correction the 80 per cent leading-power-factor type is of great advantage in construction-job power systems to help counterbalance the effect from a large number of low-power-factor induction motors; power-factor correction often leads to obtaining a better price for power from the power company. Because pure synchronous motors have no starting ability, they are frequently supplied with special

added windings which make them start as induction machines. Synchronous motors with separate motor-driven exciters and reduced-voltage starting equipment are generally used to drive air compressors. Similar motors with across-the-line starters and direct-connected exciters usually drive the generators in motor generator sets.

From the standpoint of speed ratings the following types of motors are available: constant speed; adjustable speed; varying

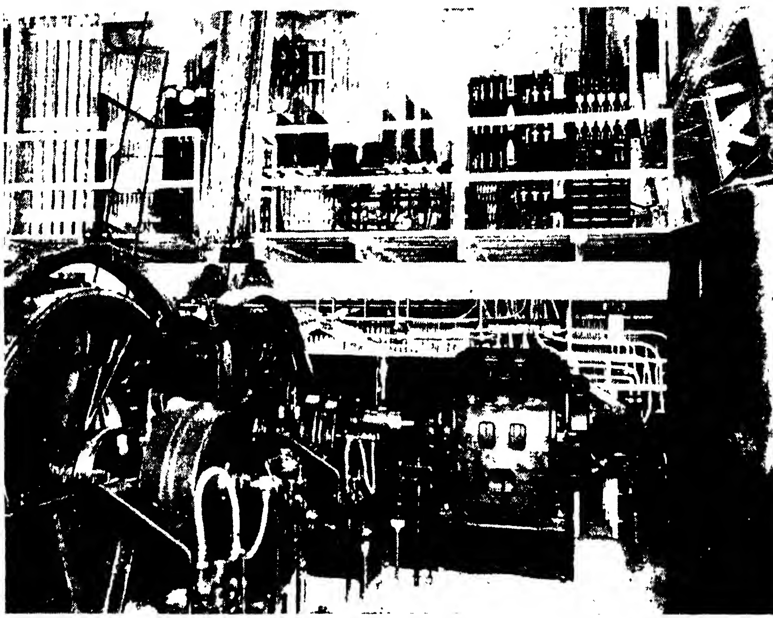


FIG. 156.—Electrical equipment for cableway hoist: 400-hp. motor, 2,300-volt control panels, and resistors.

speed (with load changes); adjustable varying speed; and multispeed. Furthermore, motors are classified by their external features in mechanical construction as follows: open; dripproof; protected (semienclosed); semiprotected; splashproof; separately ventilated; self-ventilated; totally enclosed; totally enclosed, fan cooled; explosion proof; and submersible; and their internal features through special insulation as follows: fume resisting, submersible, temperature resisting, moisture resisting, acid resisting and abrasive and conducting dust resisting.

Direct-current motors are not used so commonly on construction work because most power systems furnish alternating cur-

TABLE 56.—THREE-PHASE MOTOR APPLICATIONS FOR CONSTRUCTION WORK

1. SQUIRREL-CAGE INDUCTION MOTORS

NEMA class	Characteristics	Horse-power range, manu-facturers' standard	General characteristics, per cent of full load			Speed regula-tion, per cent slip	Starting and control equipment	Load condition	Typical equipment applications	
			Start-ing torque	Starting current	Break-down torque					
A	Normal torque Normal starting current	5 hp. and smaller	125 to 250	450 to 600	200 to 225	3 to 5	Across-the-line starting; where excessive current peaks are objectionable use reduced-voltage starting	Constant speed; continuous duty; practically constant torque requirements; starting torques should be within values given	Fans; tool and metal grinders	Pumps; joiners; circular saws
		7½ to 200 hp.	125 to 150	500 to 700	200 to 225	2 to 5	Reduced-voltage starting		Motor generator sets; screw-machines; planers	Shapers; blowers
B	Normal torque Low starting current	7½ to 200 hp.	125 to 150	400 to 500; 500 to 600 (40 hp. and above)	200 to 225	3 to 6	Across-the-line starting	Same as above, except low starting current is a necessity	Pumps (centrifugal); milling machines; lathes; buffers	Drill presses; bar bender
C	High torque Low starting current	3 to 200 hp.	200 to 250	400 to 475; 40 hp. and above,—500 to 600	275 to 225	3 to 6	Across-the-line starting for small motors, or unloaded conditions; for larger sizes use reduced-voltage starting	Same as above, except where applied load requires higher values of torque	Conveyors; crushers; bolt mills; hammer mills; vibrating screens; car pullers	Bucket-type elevators; concrete mixer; air-compressor; pumps (reciprocating); grinders
D	High torque High slip	2 to 50 hp.	200 to 300	300 to 400	200	10 to 20	Across-the-line starting, or primary resistance control, with master switch	High starting torque requirement, intermittent duty; when used with primary resistance control, provides controlled speed and acceleration	Propelling equipment for gantry cranes; elevators; lifts; hoists; small cranes	

2. WOUND-ROTOR INDUCTION MOTORS

Constant speed	1 to 200 hp.	160 to 240	Determined by required torque for starting and control resistor classification	200 to 300		Primary starting switch with secondary rheostat; or drum switch and resistors for starting duty only	Continuous duty; high starting torque; controlled starting current; controlled acceleration of load a requirement	Conveyors; air compressors; in general, all applications as given for squirrel-cage motors, where controlled acceleration is a necessity
Adjustable varying speed	1 to 200 hp.	160 to 240	Same as above	200 to 300		Same as above, except resistors rated for variable speed duty	Same as above, except speed adjustable in steps	Rock drills; rock crushers; concrete mixers; dredge machinery; blowers; fans
Adjustable varying speed Regenerative braking service	3 to 200 hp. To 500 hp. and up	160 to 275	Same as above	200 to 350 Special up to 400		Same as above, for variable-speed duty, intermittent rating	Same as above, for adjustable speed, except intermittent duty	Hoists; cranes, whirler; shovels; derricks, hoist and swing; cableways

3. SYNCHRONOUS MOTORS

		Starting torque	Pull-in torque	Pull-out torque				
80 per cent leading power factor, mainly for power-factor-correction use; constant speed; poor starting torque	20 to 5,000 hp.	40 to 200	40 to 200	140 to 400		Across-the-line, reduced voltage, or part winding starting; control equipment usually specially designed for each particular application incorporating the required protective and control features; requires separate excitation	Continuous duty; constant synchronous speed; constant or fluctuating torque; operates with high efficiency	Air compressors; ball mills; crushers; hammer mills; pumps; ideal for compressor drives and all conditions of constant-speed load service; blowers; fans; line shafts

rent, and in shifting from one project to another the investment in d.c. equipment would be uneconomical. However, d.c. motors have very desirable characteristics, particularly for construction service, and sometimes find special applications. Direct-current motors come in series, shunt, and compound-wound types. The series motor is used where a high starting torque and rapid acceleration are required, as on streetcars and similar services. The speed rises as the load drops. In shunt-wound motors the speed is practically constant at various load conditions, but the starting torque is lower. In the compound-wound motor of the cumulative type, the characteristics of the series and shunt motors are combined to give a high starting torque with a speed which does not vary greatly with load. The following characteristics are representative of d.c. motors, the figures being in terms of percentage of full load conditions. The d.c. shunt motor has a starting torque of 180 per cent, a starting current of 170 per cent, and a maximum pull-out torque of 225 per cent. The d.c. compound-wound motor has a starting torque of 200 per cent, a starting current of 170 per cent, and a maximum pull-out torque of 300 per cent.

Starting and Control Equipment.—The control equipment for the various types of motors deserves special analysis so that standardization can be practiced as far as possible, thereby allowing the various operators who handle the equipment to develop a familiarity all along the line.

Because of its simplicity, across-the-line starting is generally used in construction work on motors up to 100 hp., although 50 hp. is the desirable limit. Under certain loading conditions reduced-voltage starting may be necessary. Above 50 hp., wound-rotor motors, with equipment to control acceleration or speed, are commonly employed. Certain applications require special control equipment which must be designed to agree with the duty cycle of the driven equipment; this requires a special study of the load conditions.

The combination fusible magnetic switch of the weatherproof type, with protective equipment, offers the advantage of low installation cost for induction motors in construction work.

The control equipment for either squirrel-cage or wound-rotor motors may be of the manual, semimagnetic or full magnetic type. The latter two offer the advantage of push-button

control, whereby the speed control of a wound-rotor motor during acceleration can be made entirely automatic. Manual control on a large motor is obtained by using a drum controller or master switch with resistors.

The Ward Leonard system of electric drive and control is used on special construction machinery such as hoisting units, cranes, or shovels, where the desirable characteristics of d.c. equipment offer a substantial improvement in efficiency of operation to offset its greater expense. On an a.c. job system the power is first delivered through a motor generator set having multiple generators which generate direct current, and each one drives one of the hoist motors. Speed control of the hoist motor is obtained by varying the field current in the generator, and this offers a simplification of control, doing away with a large amount of auxiliary control equipment with its attendant possibilities for interruption.

Interlocks and Signal Systems.—A matter of great importance on construction work is the use of interlocks for certain operations such as conveyors feeding from one to another and into screens and crushers so that if failure should occur at any point the system feeding to that point is automatically stopped, thus preventing unnecessary piling up of material. At Hiwassee Dam, where a long series of operations is interdependent in the screening and crushing system, the control equipment has been designed so that the equipment must be started at the plant output end. In other words, the last motor is started first, and in this manner the entire plant is successively brought into operation. Furthermore, the interlock wiring is so arranged that if any motor is stopped, either purposely by an emergency stop button, or by electrical or mechanical failure, all equipment supplying material to the point of failure will automatically stop and all equipment beyond the point of failure will continue to empty itself. Under this system, the point of failure is automatically indicated and permits making prompt repairs without searching over the entire system for the electrical or mechanical defect.

The use of signal lights, bells, horns, and similar devices plays an important part in keeping the various interrelated features of a plant in proper function. Throughout the crushing, screening, and sand plant at Hiwassee Dam, central control stations

are provided for the benefit of operators in controlling sectionalized groups of motors. Various signal lights mounted on panels in front of the operators show, in their "on" condition, that motors in other sections are running satisfactorily.

To cut down dust in screening plants, ventilating fans must be started before crushing equipment is placed in operation. At Hiwassee this has been so arranged that in case the crusher or any other dust-producing equipment is started before the ventilating fans, a horn will blow; also, should the fan stop accidentally, the horn will blow.

Lighting.—The work-area lighting is almost entirely of a temporary nature, since it must move with the concrete-placing operations, which may be at extreme ends of the dam within 24 hr. A simple but effective type of lighting is therefore essential.

Where cableways are used to span the work a very good system of lighting consists of one or two strings of lights suspended from the cableway towers and spanning the entire work area. Such lights are high enough in the air to flood the working area, and travel with the towers. The lights are usually 1,000 watts at 200-ft. centers, suspended on hangers with rollers which ride on a messenger cable. They are tied together so the entire string can be pulled in at one end for servicing. Only a limited amount of local supplementary lighting is needed with this system.

For yard lighting and for construction roads, sodium-vapor lights are finding favor; they produce a yellow light without glare, have fog penetrating qualities, and are low in power consumption.

CHAPTER XXVII

HUMAN RELATIONS

At one of the recent conventions where the latest models of construction machinery were on display, representing the last word in efficiency, greater speed, and labor saving, one huge and awe-inspiring machine was attracting special attention, and within a relatively short time three interesting comments were overheard:

The first one came from a laboring man: "My God! look at that contraption. That will put 200 men out of work."

A county engineer came along and, after gazing at the machine, remarked to his neighbor, "If we had one of those machines in our county we could keep it going for a long time and put a bunch of our men to work."

Finally, a third man came along, his eyes beaming with enthusiasm, and he was heard to remark, "This may be the forerunner of the type of machinery which will be necessary for the construction of superhighways across the United States. If we can bring the cost of highway construction down by such devices we will some day see such work going forward on a larger scale than was ever seen in this country."

The first man was thinking of himself and of today; the third man was thinking of the future. The viewpoints of both men deserve careful recognition.

Trend of Mechanization.—As was pointed out in Chap. I, the future of heavy construction will depend largely on new developments in plant and procedure which will spell lower costs, and the construction industry will continue to move in the direction of greater mechanization. The National Resources Committee in June, 1937, reported that "While mechanical power has been instrumental in separating the worker from his tools and agriculture from industry, it has definitely created more callings and more employment than it eliminated." Although this statement is fundamentally sound, it is not enough

to accept it without considering related problems of employment.

The heavy-construction industry is, at best, a field where employment is at all times on a temporary basis. Even though a large job may last several years it eventually comes to an end, resulting in the necessary scattering of workers to other regions and attendant losses and disruption of a competent organization. Greater mechanization will lead to a reduction in the number of men required on a job or may eliminate certain classes of labor entirely, but at the same time it will result in increasing the wages of the equipment operators. The housing and sanitary facilities for employees engaged on projects in remote localities will improve as the demand for a great number of such facilities is reduced. In the end all this will produce lower costs. The construction industry can best contribute to the permanent stability of employment and national economy by reducing costs to a point where a greater number of important structures and improvements can be erected which will give new opportunities to the inhabitants of the regions where such projects are undertaken.

A striking example of this trend is shown in the case of the construction of the All-American Canal in California, which is 80 miles long and will cost $40,000,000. This canal, when completed, will provide new agricultural opportunities and other means of livelihood for a large number of people for generations to come. In the old days, when horse-drawn Fresno scrapers were among the standard methods of earth moving, cost and the time required made the construction of this canal prohibitive. Under modern methods, using machines which under the control of a single man move 12 to 14 cu. yd. of earth every minute, the canal can be built within a period of only a few years and for about one-third of the cost.

Another example of a vast project made possible by improvements in mechanization is the Colorado River Aqueduct. Here a type of tunnel construction which formerly cost between $1,200,000 and $2,000,000 per mile is now being done for $600,000 per mile. A crew of 10 men can drive a large tunnel a distance of 10 ft. within 8 hr., thus making possible speed and production records which were unheard of even a few years ago.

Lower construction costs, the use of electric and other types of power and new metals will inevitably open up new possibilities

in the field of construction which can now merely be discussed in terms of prophecies. To cite a few examples, we need only consider some of the needs of the country which will soon be upon us or are already serious limitations in our present day life: Transcontinental superhighways, with special consideration for safety-with-speed; railroad realignments to improve speed and comfort of travel; subways and other street-traffic eliminations in large cities; tunnels for water supplies, railroad, and highway improvements; canals for water diversion to improve agricultural opportunities; flood-control measures of all kinds; harbor improvements; as well as the much-discussed housing programs on large scales, and the construction of buildings of all kinds.

Based on his own muscular ability, a laborer's productive ability is considerably less than that of a horse, and his earning capacity is in about the same class. His status improves as he acquires the ability to use tools and machinery. The modern approach toward mechanization utilizes labor-saving and automatic devices wherever lower unit costs can be obtained thereby. The privilege of using the most efficient tools and methods carries with it an obligation to help in the readjustment of the workers who may be adversely affected thereby. Although our workmen are, in general, capable of readily shifting around in different types of work and to different localities, it would be a short-sighted policy on the part of employers to dismiss the problem of the working men on the basis of this fact. It would be equally serious to deny employers the necessary latitude under which such obligations can best be met.

Further dangers arise if sudden increases or excessive wage rates are introduced before the construction industry is able to absorb them under existing highly competitive conditions, because the inevitable result is that mechanization is accelerated and forced on to the industry in such a manner as to affect adversely those who were to be benefited by the increased rates. In a field where arbitrary or unsound wage rates exist, simple economics will dictate either the adoption of less efficient methods, which may, however, spell lower costs by doing the job some other way, or the invention of some new and radically different method, or they may lead to a decision to redesign the structure in order to eliminate as far as possible certain trades which demand an excessive wage. Conflicts arising in these matters

can be adjusted as long as everyone concerned maintains an attitude of reasonableness.

Another question which may accelerate mechanization if the answer is unfavorable is: "Will the workman be as dependable as a machine?" Any arbitrary and unwarranted shutdown of an operation which is part of a long series and which may be the key to continued employment for a large number of other workmen will lead to very active and definite efforts to mechanize the most vulnerable point. It is, of course, equally important that the employer be dependable from the viewpoint of the worker.

Welfare of Employees on Construction Jobs.— On most large construction jobs it is now almost standard practice for constructors to recognize certain obligations toward the community which they are about to assemble for a new project, by providing such basic facilities or necessities as sanitation, electric power and light, ice, garbage disposal, health and safety measures, a school, forms of amusement, and similar facilities. The personnel of the heavy construction industry is composed of many exceptionally capable and widely experienced craftsmen and workmen of all kinds, and in following their trades they are obliged to shift over the country from job to job as one is completed and another one started. The ability and quality of these people are often superior to those found in other industries where the workmen are privileged to enjoy the opportunities of a more stable community life. Many constructors have looked forward to the day when they can provide for their employees those facilities of community life which will assure a standard of living more in keeping with the quality of the employees and their families, and under which the children of such families can pursue the normal opportunities to which they are entitled and which diligent workmen are constantly striving to obtain for their families.

During the past decades there have been marked improvements in this respect, but the contractor who is obliged to bid on a competitive basis for his work can go only so far in the type of facilities which he includes in his bid; otherwise he faces the danger of losing the job. Some important contributions in this respect have been made by public agencies and owners for whom the projects are being constructed, by stipulating in their specifications and contracts that more extensive facilities and

better living conditions be provided. Such agencies are willing to pay the additional costs resulting from these demands. It is safe to say, however, that contractors who are in a position to house their employees in good quarters and give them a better standard of community life are able to give the client a substantial and definite return in the form of better progress and better quality of workmanship.

"Safety First."—Remarkable progress has been made in recent years in educating workers in the matter of safety for themselves and for their fellow workers. The process of making them "think" is a never-ending obligation. In addition it is imperative to provide all feasible safeguards in the form of covered passageways, gear covers, safe stairs and ladders, and such appliances as goggles, respirators, safety shoes, life-preserver vests, etc. First-aid treatment for emergencies, a well-equipped hospital, and disability compensation are now standard features of a well-run job.

Building an Organization.—Although this book has discussed primarily the construction plant and its importance on large projects, we must not lose sight of the men behind the machines and the general organization required to put the job across. There is nothing more important than a competent organization which has been working together for a long time and always comes back to the fold when a new job is ready to start. In such an organization every man knows what his part of the job is, what is expected of the next man, and how to work together and cooperate for the greatest common good.

The able contractor is continually trying to keep his organization built up to par and to find new leaders. He must at all times maintain a proper balance among apprentices, helpers, skilled men, straw bosses, and foremen on up to assistant superintendents and superintendent. As long as he seeks to grant adequate reward for meritorious work and to encourage advancement from one step to another he is certain to have a competent and loyal organization. This may even be augmented by a definite training program in order to assure the process under which a future superintendent comes up through the ranks. The leaders who are developed in this manner thoroughly understand their obligations to the men under them and they also understand the individual problems of their men.

This process of recognizing ability and helping able men to get ahead is the best means of building up initiative and skill throughout the organization and is fundamental to the development of a more stable construction industry.

The contractor and his superintendent have great responsibilities and obligations toward their employees. They are obliged to entrust the safety of large bodies of men to others, such as foremen, straw bosses, truck drivers, locomotive runners, and hoist runners. This requires implicit confidence and cooperation and a thorough knowledge of the past record of employees who are entrusted with such responsibilities. Here again the effect of the continually growing and improving organization rising up from the ranks leads to the best feeling of responsibility and obligation among the men toward each other.

Transition in Labor Relations.—It seems unfortunate that the classification of men into two groups of labor and management is sometimes carried to such extremes that it results in unnecessary disputes, antagonisms, and petty grievances which are built up to the point where they destroy confidence on both sides, with the inevitable result that many competent men, through their own or directed acts, are denied their normal opportunities. Arbitrary mass action or coercion breaks up an organization, destroys morale, and inevitably diverts the responsibility of the employer regarding the welfare of his men. The welfare of labor depends on the welfare of the employer, and if the employer is denied the opportunity to meet competitive conditions his entire organization suffers the loss.

In discussing employee relationship problems recently with a manager of a large company which had experienced no unrest or labor troubles, whereas some other companies in the same industry were confronted with serious disputes, the manager explained: "We have attempted at all times to anticipate the reasonable needs of our employees and to provide for them in such a manner that they have no occasion to become dissatisfied." Such provisions consisted of improved housing conditions, community entertainment facilities, good working conditions, sanitary and health measures, and definite efforts to meet such problems as unemployment, seasonal reductions in force, and security during old age.

Many labor disputes over small matters grow to unreasonable proportions simply because of the way they were approached or because of the arbitrary manner in which settlement was attempted. A contractor owes it to his men to approach the settlement of a dispute in a manner which will generate confidence and assurance that they are getting a fair deal. Labor disputes have been known to exist for some 600 years and no doubt they will exist for many centuries to come, but as long as they are handled in a fair and considerate manner there should be little occasion for disruption and serious consequences.

One of the great obligations which a contractor, manager, or supervisor has on a construction job is to understand his men. Many times, if he understands the worries of an individual, he may be able to encourage him in a manner that will produce lasting benefits. Frequently he can shift a man from one job to another and help the man to find himself "by taking a square peg out of a round hole" and giving the man a new chance. Adjustments made within the organization invariably lead to better feeling and encouragement and are far more effective in avoiding stagnation than the arbitrary process of infusing new blood.

On one large job a great improvement in morale occurred by announcing that, in case layoffs were necessary due to curtailment of work, at least one week's notice would be given. This promptly placed the conscientious and reliable men in a separate category from the shirkers and those who were apt to violate established rules for which they were liable to face immediate dismissal. Not only was this atmosphere of recognition established, but the worry of living on the job from day to day without any feeling of security was eliminated.

In closing it may be well to enumerate certain points which must at all times prevail if the construction industry is to move forward for the greatest common good:

1. Operate at maximum efficiency and skill of the constructors.
2. Build at lowest possible cost to the owner.
3. Pay highest possible wages consistent with a sound position for the industry.
4. Provide the best possible and safest working conditions for the men.
5. Promote greater continuity of employment.

6. Assure the opportunity for developing initiative, skill, ambition, and loyalty of every employee.

7. Assure unhampered means for honestly recognizing and rewarding meritorious work and initiative.

8. Assure the opportunity for advancement and the constant building up of a better organization from apprentices on up.

9. Help to promote greater self-sufficiency and independence for every man.

10. When you engage a man's services be sure you also engage his good will.

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